

**DESIGNING SERVICE OPERATIONS:
VALUE (ECONOMIC AND ENVIRONMENTAL)
IMPLICATIONS**

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**DESIGNING SERVICE OPERATIONS:
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IMPLICATIONS**

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To my parents (and personal heroes), Vasili and Kiki
and to my brother Vaggeli.

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SUMMARY

The service sector has been identified as the main force of economic and potentially sustainable growth in most developed economies (Rothenberg, 2007). Nevertheless, despite the role of services in today's economy, little is known about what drives service innovation and which tools and methods determine successful service design and development. This dissertation focuses on addressing the challenges associated with the design, development and operation of service offerings. In the first essay (Chapter II) we explore the design challenges of an organization that develops an experiential service. In experiential services, the customer value extends beyond the functional benefits of the service, and it encompasses the overall experience. We draw upon the perspective of the customer journey, which is widely used by design firms (e.g., IDEO), and we model the entire service experience as a process comprising individual service steps (also known as *touchpoints*). The value of the service is “co-produced” over several touchpoints between the customer and the service provider. We identify the non-monotonic effects of the co-production losses and service complexity on the provider's design decisions, (i.e., price), and the touchpoints she controls. Finally, we fully characterize the conditions under which the service provider may use these design decisions to effectively signal the experience potential of the service offering. In the second essay (Chapter III) we study the auto manufacturer's choice regarding whether to provide mobility service (e.g., car sharing) in conjunction with the traditional sales channel. A utility maximization model is used to characterize the consumer's choice between purchasing a vehicle, benefiting from the mobility service or relying on an outside option (e.g., public transportation). We characterize the benefit to the manufacturer of providing mobility service and the environmental

implications of this strategy. In the third essay (Chapter IV) we study the implications of “reference point” effects on the optimal service design. We envision the service delivery as a two-stage process in which customer satisfaction is stochastic. The service provider needs to determine the optimal level of effort to exert at each stage, given that the customer experience at the first stage of the process can affect the expectations regarding the experience at the second stage of the process.

CHAPTER I

INTRODUCTION

In recent years, the competitive landscape in which firms operate has undergone a revolution in character. One of the main drivers of this change has been the fact that many firms and economies are shifting from product-oriented to service-oriented markets (Insight, 2007). This transition is further illustrated by the entry of traditionally manufacturing-focused organizations such as IBM, Kodak, GE, and GM into business and financing services (Sawhney et al., 2003). The service sector has been identified as the main force of economic and potentially sustainable growth in most developed economies (Rothenberg, 2007). Therefore, the need for successful design and development of services has emerged as a crucial business element. Yet, despite the role of services in today's economy, little is known about what drives service innovation and which tools and methods determine a successful service design and development. Frei (2008) observes that most service-focused firms rely on tools that were designed to tackle the challenges of product-focused companies. Most of the NPD tools, however, do not address the challenges unique to the nature of services (e.g., customers' involvement in the value creation process; see Sasser, 1976); therefore, their application to new service design and development is rendered problematic. This dissertation focuses on addressing the challenges associated with the design, development and operation of service offerings.

In the first essay presented in Chapter I, we explore the basic challenges that an organization faces in the design and introduction of an *experiential service*. In experiential services, the customer value extends beyond the functional benefits of the

service, and it encompasses the overall experience. We build upon the *customer journey*, a widely adopted concept in service design, which views a service as a collection of interaction *touchpoints* between the customer and the service provider that create a holistic experience. We model the service experience as a process comprised of sequential touchpoints, and we focus on the provider’s design decisions: the number of service touchpoints she chooses to control, and the price she charges. Our results reveal the non-monotonic effects of the interactions between the provider and the customer. These interactions may assume the form of losses (due to the difficulty to fully match the customer needs), or they may determine the subsequent experiences (touchpoint dependencies). We fully characterize when the service provider may use the service design to effectively signal her true underlying capability in service provision. A separating equilibrium can be attained depending on the capability as proxied by the cost structure: the “capable” type provider successfully reveals her type either by signaling expertise (i.e., controlling fewer touchpoints) or by signaling efficiency (i.e., controlling more touchpoints). The service price is used only as a signaling mechanism of last resort. Yet, as the value associated with capability increases a pooling equilibrium dominates.

The second essay presented in Chapter III is motivated by the observation that, in recent years, manufacturers from various industries have begun to orient their practices towards the provision of solutions (e.g., mobility, lighting, carpeting solutions) as opposed to strictly selling their products. This trend, known as servicization, reveals the transition from a product ownership economy to a functional or service economy. Servicization is characterized by the emergence of product-based services, also known as Product-Service-Systems, which blur the distinction between manufacturing and traditional service activities. Product-Service-Systems can be thought of as a market proposition that extends the traditional functionality of a product by incorporating additional services. Here the emphasis is placed on the “sale of use” rather than the

“sale of product.” In this essay, we examine the extent to which such practices exist in the transportation business. Solution-orientated models in the transportation business are mainly manifested through leasing, rental, and membership schemes. Interestingly, we observe significant differences in the popularity and maturity of such models between the private jet and automobile industries. For instance, the private jet industry has explored a variety of options, with a number of jet manufacturers offering the full spectrum from selling and leasing to jet membership. Only recently, big auto manufacturers (e.g., BMW) announced their intention to expand the scope of their business by introducing car membership schemes (Fuhrmans, 2010). The novelty and increasing popularity of the car sharing business models, along with the growing interest of the business press, motivate us to explore such models (e.g., Zipcar). In this essay, we focus on the auto manufacturer’s dilemma regarding whether to sell a product, provide a mobility solution, or do both. We use a discrete/continuous demand model to capture consumers’ self-selection and usage optimization decisions, which serve as input to the manufacturer’s problem. Through our numerical analysis we are able to characterize three different decision levels. Specifically, by going backwards we characterize i) customers’ usage adjustment, ii) customers’ (discrete) choice of transportation mode, and iii) manufacturers’ production and price decisions. With respect to the latter decision level, the manufacturers’ production decisions encompass the number of vehicles offered through a traditional selling and/or membership scheme, and price decisions encompass the vehicle selling price and the membership fee. The environmental implications of such Product-Service-System are also assessed.

The third essay, presented in Chapter IV, studies the implications of “reference point” effects on service design by utilizing a process-based view of services. The novelty of the process-based view of services (also adopted in Chapter I) resides in the realization that, in services, customer value is not generated solely during the

transaction point or the “core” offering of the service. Under this new conceptualization, a service provider can decide how much effort to allocate not only at the transaction point but also before it. In order to increase the likelihood of customers joining the service system, the provider may exert costly effort before the “core” of the service without obliging the customers to commit to a price. However, customers may form and anchor to an “experience reference point.” Provided that customers decide to join the service system, experiences at the “core” offering that fall below that reference point can cause customer disconfirmation, which negatively impacts the provider’s profit. In this context we formulate and characterize the optimal effort allocation decisions of the service provider.

CHAPTER II

THE DESIGN CHALLENGES OF EXPERIENTIAL SERVICES

2.1 Introduction

Consider a restaurant enthusiast visiting the city of San Diego, CA. During his visit, he can choose among a variety of dining establishments, like the the Gaslamp Club A Steak Place, located in the vibrant Gaslamp district. This well-known Californian steak lounge lets the customers “grill their own selection of steak” and thereby delegates the food preparation responsibility to them (Cohn Restaurant Group, 2011). Nevertheless, the meat selection is tightly controlled by the restaurant chef to ensure superb quality. Contrast this service experience with another equally unconventional restaurant experience: the Real Chow Baby restaurant, in Atlanta, GA. There, customers choose from a wide variety of different ingredients and prepare a combination of their own inspiration. Then, they let the chefs assume the cooking responsibility based on generic guidelines (e.g., medium-well cooking; The Real Chow Baby Team, 2011).

Design differentiation across service offerings is a common practice across business settings. Providers choose different designs to cater to the same customer need (e.g., to dine or rent movies), in an effort to drive commercial success. In the movie rental business, Netflix revamped the traditional process, as represented by Blockbuster.¹ In essence, Netflix assumed responsibility for a part of the service process that Blockbuster did not. For instance, Netflix customers received weekly email updates about

¹This was the case until August 2004. Then, Blockbuster launched an online DVD rental service (CNET News, 2004).

new releases, while Blockbuster customers relied on their own independent sources of information (e.g., word of mouth).

The design of service offerings, however, presents unique challenges: customers interact with the provider during the service delivery process in complex and uncertain ways to *co-produce* the service outcome (Sasser, 1976). Thus, the realized customer value often extends beyond the functional benefits of the service task, and it encompasses the overall interaction experience. High experiences may vary depending on the objective of the service offering. Customers may appreciate the streamlined efficiency in service completion (as in Netflix’s case), or they may enjoy the high quality of the service output (as in the Gaslamp restaurant case). At the same time, it is extremely hard for a customer to know *a priori* the capability of a provider to offer such a high experience, especially for new service offerings. Therefore, the presence of information asymmetry further complicates the customer-provider interaction and hinders the design decisions.

In response to these challenges, service providers actively account for the customer perspective (Chase and Dasu, 2001; Frei, 2008) during the design process to capitalize on the experiential component of the service (Pine and Gilmore, 1998; Voss et al., 2008). Design firms like IDEO (Bhavnani and Sosa, 2006) employ an approach that systematically captures the “determinants” of the customer experience: the *customer journey* (Richardson, 2010a,b,c; Gamerman, 2011). The origins of the customer journey concept can be traced back to Shostack (1984) and the *service blueprints*. Each *experiential service* is represented as a journey during which the customer satisfies his need(s) through distinct experiences created at consecutive stages (i.e., touchpoints, also termed service encounters; Roth and Menor, 2003). The overall customer experience results from the accumulation of touchpoint experiences. Through the customer journey, designers question whether they should create more or fewer touchpoints by controlling parts of the service encounter, and therefore by enabling interaction with

the customer. The usefulness of the customer journey perspective has been advocated in a variety of service contexts. For example, Vossoughi (2010) argues that in health-care services the lack of consideration of the *patient journey* has resulted in service task fragmentation and has compromised the patient experience.

In this paper, we develop a model to capture the design challenges that a service provider (henceforth “she”) faces in an experiential service. The provider’s main design decisions include the selection of the customer journey touchpoints that she controls and the price she charges for the service. A successful service offering strives to balance two forces: the downside that the customer (henceforth “he”) may experience due to the uncertain outcome of a customer-provider interaction and the experience benefit that a potentially capable provider can offer. Even in the absence of information asymmetry, we find that the optimal design decisions depend non-monotonically on two important parameters: i) the variability of the experiential outcome from touchpoint interactions and ii) the underlying interdependencies between the service tasks, which may give rise to *correlated* experiential outcomes across touchpoints. Even when the provision of the entire customer journey is costless, the service provider optimally chooses to control only part of the journey, as long as some touchpoint interdependencies exist.

When information asymmetry is present, we outline conditions under which the service provider uses the service design to signal her capability to offer high experience. Our results indicate that a service provider signals her capability through different service designs depending on the service objective. When a high experience is associated with a streamlined, cost-efficient process (i.e., the provider can complete the service tasks at a lower cost), then she credibly signals her capability through an extended set of touchpoints. By contrast, when high experience reflects the customer appreciation for the outcome quality of the service task (a feature of expertise-based

but costly provision), signaling takes place through a focused offering on key touchpoints. Under certain conditions, the choice of touchpoints is inadequate to signal the provider’s capability, and therefore she resorts to pricing as a signaling mechanism.

2.2 Literature

Our work draws upon two streams of research in the service management literature. The first stream studies the role of customer involvement in the design decisions of a service provider. The second stream analyzes the operational implications from different customer-provider interactions.

2.2.1 Service Design and the Role of the Customer

Customer engagement during the service delivery process has been identified early on as a challenge unique to service environments (Sasser, 1976). A series of studies has tried to determine whether customer engagement is beneficial or detrimental to the service provider. On one side, Chase (1978), Chase (1981), and Chase and Tansik (1983) argue that further customer participation comes at the expense of operating efficiency. On the other hand, Lovelock and Young (1979) suggest that customers can be an indispensable source of labor that may lead to productivity gains for the provider, to the extent that customers can be viewed as “partial” employees (Mills and Morris, 1986). Shostack (1987) is the first to argue that the effect of customer participation in the service outcome is not unequivocal and needs to be carefully incorporated into the service design. In two influential articles (Shostack, 1984, 1987), she proposes that every service offering can be mapped as a process consisting of distinct steps, and through such a breakdown the provider can identify where to improve the interaction and further engage the customer.

This stream of research serves as the theoretical foundation of our work. We contribute to this area by formally modeling the service design decisions as dependent

on the degree of customer involvement.² We identify customer involvement to be positive or negative depending on two important parameters: the variability of the customer-provider interaction outcome and the interdependencies among the service tasks.

2.2.2 Service Design and the Role of Operational Variability.

The Operations Management literature has extensively studied the effect of variability in service systems. Specifically, customer involvement has received attention as a primary source of variability. We classify this stream of literature into studies that have assumed service systems composed of either a single stage or multiple stages (i.e., touchpoints in our context).

Modeling services as a single touchpoint: studies close to our setting (Debo et al., 2008; Anand et al., 2011), conceptualize service design as the selection of price and service rates. Then, customer involvement is only determined through the adjustment of the customer arrival rate. An exception is Ha (1998), who conceptualizes customer involvement through the choice of their own service rate. However, such self-optimization behavior results in socially suboptimal service rates due to increased congestion effects. Still, remedy through the proper design is constrained only to pricing decisions. However, such a conceptualization of customer involvement only mitigates the congestion effects and never benefits the provider. Conversely, we do not “predispose” the provider against interaction with the customer. In experiential services, customer involvement extends beyond the congestion effects and it may drive higher or lower service experiences.

Modeling services assuming multiple touchpoints: most studies in that stream consider only two touchpoints to rein the mathematical complexity (Shumsky

²Recent studies (Xue and Field, 2008; Roels et al., 2010; White and Badinelli, 2010) analyze formal contractual implications for the customer-provider interaction. Instead, we consider settings where formal contracts would be difficult to enforce, and we analyze how the service design decisions depend on the nature of the customer-provider interaction.

and Pinker, 2003; Lee et al., 2009). However, they do not consider any customer engagement. An exception is a study by Xue and Harker (2003) who consider a two-stage service process comprising two servers in tandem. At the first stage, the provider allows customers to perform self-service tasks. Then, she lets them join the queue of the second stage performed by her. Due to the exogenous nature of customer efficiency and firm cost structure, the provider either engages the customer fully or not at all. We contest this finding in our analysis.

Similar to all these studies, we acknowledge the provider’s decision to get customers actively involved during the service as well as the presence of variability in most service systems. Nevertheless, we do not restrict our attention to stochastic arrival or service rates as possible sources of variability. Instead, we recognize that in experiential services the effects of variability may stem from more fundamental sources such as the nature of the customer-provider interaction and the underlying structure of the service tasks.

2.3 *The Model*

In this section, we outline the model assumptions, namely the context of the service, and the structural elements of the provider’s and the customers’ decisions.

2.3.1 Service Context

Ulrich and Ellison (1999) suggest that the design of products and services benefits more from a “holistic” perspective, that is, the entire set of actions and decisions that a consumer undergoes in order to satisfy his need. Within experiential services, the concept of *customer journey* (Bhavnani and Sosa, 2006; Voss et al., 2007) offers such a perspective. It proposes that the customer experience builds cumulatively over several touchpoints, much before and after the transaction touchpoint, a core focus of the traditional service design.

We formalize the customer journey as a set of n distinct steps, i.e., $\mathcal{J} = \{1, 2, \dots, n\}$

that aim to satisfy a specific customer need and create a high experience. The definition of a high experience is contingent on the objective and the nature of the service task. The service objective may represent a streamlined, cost-efficient task completion, or the high quality outcome of a service (Parasuraman et al., 1985, 1991). Service providers may exhibit different capabilities in ensuring high experiences. Thus, a provider can be of type θ and exhibit high ($\theta = H$) or low ($\theta = L$) capability in offering high experience.³ At the same time, the service touchpoints may create interdependent, complex effects on the customer’s experience⁴ at a specific touchpoint due to the nature of the service tasks. Therefore, the experience that customers obtain at the completion of the i^{th} touchpoint may depend on prior realized experiences.

For instance, consider a visit to a health care provider. If early on the nurse fails to fully understand and record the symptoms and health history or the patient fails to effectively communicate that information, then the subsequent diagnostic and treatment experience will likely be imperiled. A similar situation (with hopefully less detrimental results) may occur when placing a restaurant order. A less capable *maître d’* may adversely affect the dining experience due to an order that is mismatched to the customer preference. In contrast, standardized and automated settings like fast food or bank transaction services contain fairly straightforward independent touchpoints in terms of their contribution to the customer overall experience.

2.3.2 Customer Experience

Consider a customer who seeks to satisfy a particular need (e.g., diagnosis and treatment from a health care provider), and he must go through a specific customer journey. Let us assume that each step⁵ can be performed by either the consumer himself, or

³We elaborate on this assumption in §3.3.

⁴A more accurate term would be *instant utility*. We use the terms “instant utility,” “transformation function of instant utility,” and “predicted utility” as presented and explained in Kahneman et al. (1997).

⁵In the rest of the paper we use the terms steps and touchpoints interchangeably.

an expert service provider. The per-step experience depends on the entity $e \in \{\theta, C\}$ (high, low-type provider or customer respectively) that performs it. Customers hold a prior belief $\phi \in (0, 1)$ that the provider is of high type.

We admit to a basic service reality up-front: the experience enjoyed at a service step is *ex-ante* described by a random variable $\tilde{V}_i^e \sim \mathcal{N}(V_i^e, \sigma_e^2) \forall i \in \mathcal{J}$ and $e \in \{\theta, C\}$. Through \tilde{V}_i^e , we capture the fact that it is almost impossible to predict an exact experience. The mean and variance carry a very intuitive meaning: the mean represents the systemic functional contribution to the customer experience during the service step, whereas the variance represents the idiosyncratic (interaction and moment-specific) experience gain or loss that may take place. Berry et al. (2002) refer to those two major components as “the clues that make up the customer experience.”

Regarding the functional component, V_i^e , we consider the meaningful case where the customer benefits from the provider controlling a step of the process ($V_i^\theta \geq V_i^C$). This benefit represents the added value that a dedicated provider brings (i.e., service configurations, or actions the customer may be unaware of, such as best practices in food selection, preparation, and presentation). Let the functional contribution at each step be V_i^θ where $i \in \mathcal{P}_\theta \subseteq \mathcal{J} = \{1, \dots, n\}$; \mathcal{P}_θ indicates the subset of touchpoints controlled by a provider of capability θ . Given our definition of θ we assume $V_i^H \geq V_i^L$. Additional benefits due to high capability capture the psychological safety derived when treated by a recognized expert provider. For instance, the assurance a patient feels when he thinks he is receiving treatment from a very knowledgeable doctor, or the stress avoidance that a customer enjoys knowing that he will be served fast in a deli, or the peace of mind a parent has when he presumes that his children will be kept at the best daycare. Fitzsimmons and Fitzsimmons (2007) and Roth and Menor (2003) refer to such benefits as the *implicit service* elements of a service offering. Due to his lower expertise on the nature of the service tasks, the customer realizes a smaller per-step functional experience V_i^C with $i \in \mathcal{C} = \mathcal{J} \setminus \mathcal{P}_\theta$, i.e., the subset of

touchpoints delegated to the customer.

Regarding the idiosyncratic component of the experience, we assume that each customer-provider interaction differs regarding the experience realization. For instance, the same customer may enjoy a different dining experience at a specific restaurant even if every time that he visits he is served by the same waiter, sits at the same table, and consumes the same food at the same time of the day. This random feature is a unique characteristic of service environments. It arises primarily from the fact that customers actively participate and co-create the service outcome (Voss et al., 2008). For a variety of reasons, such as asymmetric task expertise, fuzzy cross-communication, or even limited comprehension skills, we assume that the idiosyncratic component of the experience is more variable at the touchpoints controlled by the provider (Terwiesch and Loch, 2004). Thus, we assume $\sigma_C^2 = \delta \sigma_\theta^2$ with $\delta \in (0, 1)$ and $\theta \in \{H, L\}$. This variability shall not be confused with the “operational” variability introduced by customers’ involvement in the service delivery process and which can cause inefficiencies (e.g., waiting times). In our model we capture such inefficiencies through the value $V_i^C < V_i^P$. For tractability reasons we assume that the variability introduced is independent of the provider capability.⁶ Note that due to the possible interdependencies among different service tasks, the realizations of the experiences \tilde{V}_i^e across the respective touchpoints may be correlated with correlation $\rho > 0$.

To further illustrate the roles of V_i^e and σ_e^2 in our model, consider again the patient seeking diagnosis and treatment. Let us assume that the customer is currently at the *Registration* touchpoint of the patient journey. Depending on the specific healthcare provider, contemplate the following two service design scenarios: i) the customer is

⁶Our assumption is not restrictive. In fact, we capture the capability effects through the mean per-step experience, as opposed through the variance. One could envision a scenario where the mean is common across and the variance is capability dependent. We have performed additional analysis which shows that our results remain qualitatively the same.

supposed to self-check-in and self-report his symptoms and medical history by filling out all the appropriate forms, or ii) specialized personnel (e.g., nurses) are responsible for the patient’s registration. In the latter case, a nurse ensures that registration happens in a smooth and timely fashion without unnecessary trial-and-error attempts (e.g., fields missing from the registration form). Using our terminology, this corresponds to $V_{Registration}^{Nurse} > V_{Registration}^{Patient}$. However, in the event that a nurse controls the registration, the idiosyncratic component of the touchpoint experience can add or subtract customer value. For instance, a patient may perceive the presence of a nurse as rather intrusive, and for that reason he may feel uncomfortable to share details of his medical history and symptoms ($\tilde{V}_{Registration}^{Nurse} < V_{Registration}^{Nurse}$). On the other hand, it may also be possible that the patient considers the nurse helpful, friendly, and/or reassuring, and thus finds it easier to provide the necessary information ($\tilde{V}_{Registration}^{Nurse} > V_{Registration}^{Nurse}$). Since the patient’s self-registration experience is not affected by the nurse, it is reasonable to assume that $\sigma_{Patient}^2 < \sigma_{Nurse}^2$.⁷

More formally, if the provider controls the set of touchpoints $\mathcal{P}_\theta \subseteq \mathcal{J}$ and charges a price p^θ then the overall experience realization that each customer may derive from going through the entire service process is given by equation (1),

$$\tilde{V}(\theta, p^\theta, \mathcal{P}_\theta) = \sum_{i \in \mathcal{P}_\theta} \tilde{V}_i^\theta + \sum_{i \in \mathcal{C}} \tilde{V}_i^C - p^\theta \sim \mathcal{N}(\mu_V, \sigma_V^2) \quad (1)$$

with $\tilde{V}_i^e \sim \mathcal{N}(V_i^e, \sigma_e^2) \forall e \in \{\theta, C\}$ and μ_V, σ_V^2 as defined in Lemma 1 in the Appendix. Validation of the cumulative experience assumption has come from psychology research (Loewenstein et al., 1993; Ariely and Zauberman, 2003). The first term of equation (1) captures the overall experience that the customer derives from the subset of touchpoints that the θ -type provider controls. The second term expresses the experience from the touchpoints that the customer self-performs, and the third

⁷The subjective experience components are not customer specific. They do not represent a consumer “type”, and cannot be used as segmentation levers. For example, the same patient could potentially experience a $\tilde{V}_{Registration}^{Nurse} > V_{Registration}^{Nurse}$ during one visit, and a $\tilde{V}_{Registration}^{Nurse} < V_{Registration}^{Nurse}$ during another. As such the experience realization cannot be predetermined.

term is the price that the customer pays for receiving the service.⁸

2.3.3 Provider Capability

The profit-maximizing service provider can deliver high (a “high-type provider”) or low (a “low-type provider”) per step experience. Recall that $V_i^H > V_i^L$ and that the exact definition of a high experience describes different service objectives. Mapping these differing objectives to the relative magnitude of the marginal provision costs allows us to represent two important cases: when the customer appreciates streamlined service completion, we posit that he expects high experience from the provider with the low marginal provision cost, i.e., $c_H < c_L$; on the contrary, when the customer associates high experiences with a high quality outcome (e.g., a medical diagnosis), he expects these outcomes to require high marginal provision costs, and therefore $c_H > c_L$.

Given the overall context of information asymmetry, the provider’s design decision involves two dimensions which also act as signals about her capability: which touchpoints to control (\mathcal{P}_θ) and what price p^θ to charge. After observing the provider’s signal $\mathbf{m}(\theta) = (p^\theta, \mathcal{P}_\theta)$, customers update their prior ϕ to the posterior $\phi' = \phi'(\mathbf{m})$ and based on that they decide whether to seek service. The total number of customers that decide to join the provider’s service system is $M(\phi', \mathbf{m})$. Therefore, the provider’s profit function when she controls a set \mathcal{P}_θ of touchpoints and charges a price p^θ is:

$$\Pi(\theta, \phi', p^\theta, \mathcal{P}_\theta) = \left(p^\theta - c_\theta \sum_{i \in \mathcal{P}_\theta \subseteq \mathcal{J}} V_i^\theta \right) M(\phi', \mathbf{m}). \quad (2)$$

Equations (1) and (2) show how our model captures a fundamental trade-off in services: the provider can offer greater functional benefit to a customer by controlling

⁸It is assumed that the price for the service offering is guaranteed to be paid once the customer joins the service. Alternatively, we assume that the customer will proceed through all the service upon requesting the offering as he finds it prohibitively expensive to renege. The relaxation of this assumption is left for future research.

an increased number of touchpoints. Yet, as she controls many touchpoints, she assumes greater variability in the realized experiences and fails to ensure a smooth service process. Figure 1 depicts our service process, and in the Appendix we provide a summary of the notation used throughout the paper.

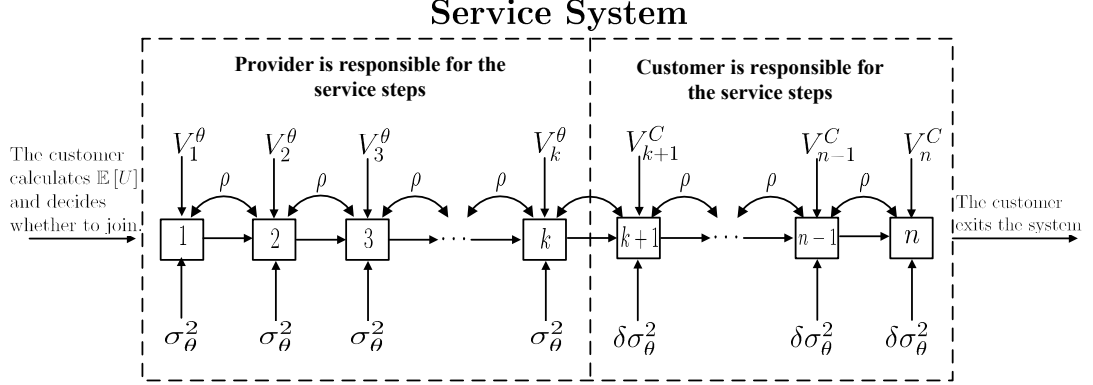


Figure 1: Customer journey in the service system. For ease of exposition, i) we assume that the service provider chooses to control the *first* k steps of the customer journey. Our analysis holds without such a restrictive assumption. ii) Only the correlation ρ between the sequential steps is shown. Our model assumes the same pair-wise correlation across all touchpoints.

2.3.4 Sequence of Events

Initially, nature selects the service provider's type $\theta \in \{H, L\}$ and the customers' prior belief ϕ . The type θ is communicated only to the provider while ϕ is known to both the provider and the customer. Both customers and provider associate high provider capability with a cost structure (i.e., $c_H > c_L$ or $c_H < c_L$). Then the provider designs the service, that is, she commits to a number of touchpoints she will control through an up-front, irreversible investment (e.g., choice of specific equipment and/or training of personnel). For a set of touchpoints \mathcal{P}_θ , the provider sets the price p^θ she will charge for the service. Recall that the customer faces uncertainty regarding the provider capability. Specifically, customers hold a prior belief $\phi \in (0, 1)$, which after observing the signal $\mathbf{m}(\theta) = (p^\theta, \mathcal{P}_\theta)$, they update to the posterior $\phi'(p^\theta, \mathcal{P}_\theta)$.

Clearly, the customer-provider interaction may result in more or less gratifying

experiences. However, this uncertain nature of the experience has adverse effects on the customers' *prior to the service* decision to request the offering. We approximate such a behavioral trait through customer risk aversion. Namely, we assume that customers prefer less variable and more uniform service experiences.⁹ We capture the customer's risk aversion through an appropriate, non-decreasing *transformation function of instant utility*, $U(\tilde{V})$. The customer observes the general features of the service and calculates a *predicted* utility $\mathbb{E}_{\phi', \sigma_P^2, \sigma_C^2} [U(\tilde{V})]$ (Kahneman et al., 1997). He enters the service system if and only if $\mathbb{E}_{\phi', \sigma_P^2, \sigma_C^2} [U(\tilde{V}(\theta, p^\theta, \mathcal{P}_\theta))]$ is greater than $\mathbb{E}_{\phi', \sigma_P^2, \sigma_C^2} [U(\tilde{V}(\theta, p^\theta = 0, \mathcal{P}_\theta = \emptyset))]$ i.e., the utility he expects to derive from self-performing the entire journey.

2.4 Analysis

We begin with the analysis of the full information case, i.e., $\phi = 1$ (no uncertainty about the provider capability). We eliminate references to a type θ and instead we use the identifier P . This analysis allows us to describe the effects of the service task parameters on the optimal design decisions, and it offers a benchmark setting. Then, we proceed with the information asymmetry setting. All proofs are detailed in the Appendix.

2.4.1 Service Design Under Full Information

2.4.1.1 Customer's Problem.

We model the customer's risk aversion with a well-grounded functional form, that is, $U(\tilde{V}) = -e^{-r\tilde{V}}$, where $r > 0$ indicates the Arrow-Pratt measure of absolute risk aversion (Varian, 1992). Given that we assume full information, the provider

⁹Contemplate the example of a customer deciding upon entering a new restaurant for the first time. Although, the restaurant experience presents an upside, it can also lead to rather painful downsides, e.g., food poisoning etc. The effect of the hedonic profile of an experience on the overall evaluation of an event has been extensively studied in the field of psychology (Varey and Kahneman, 1992; Loewenstein et al., 1993; Ariely and Zauberman, 2000).

capability is fully known when the decision to seek service is taken. A customer will seek service if and only if $\mathbb{E} \left[U \left(\tilde{V}(p, \mathcal{P}) \right) \right] - \mathbb{E} \left[U \left(\tilde{V}(p=0, \mathcal{P}=\emptyset) \right) \right] \geq 0$, where $\mathbb{E} \left[U \left(\tilde{V}(\cdot) \right) \right]$ is derived in Lemma 2 in the Appendix.

2.4.1.2 Provider's Problem.

Let \mathcal{F} be the sigma-algebra of all possible subsets of \mathcal{J} . The design challenges of the service provider correspond to the profit maximization problem stated in equation (3).

$$\max_{p, \mathcal{P} \in \mathcal{F}} \Pi(p, \mathcal{P}) = \max_{\mathcal{P} \in \mathcal{F}} \left\{ \max_p \left(p - c \sum_{i \in \mathcal{P}} V_i^P \right) M \cdot \mathbf{1}_{\{\mathbb{E}[U(\tilde{V}(p, \mathcal{P}))] \geq \mathbb{E}[U(\tilde{V}(p=0, \mathcal{P}=\emptyset))]\}} \right\}. \quad (3)$$

Without loss of generality, we normalize $M = 1$. Then, for a design configuration (p, \mathcal{P}) the provider faces non-zero demand as long as she prices below an upper limit, which depends on the selected touchpoints (Lemma 3 presents the formal argument in the Appendix). Intuitively, the provider chooses to charge the maximum possible price, $\bar{p}(\mathcal{P})$, that retains $\mathbb{E} \left[U \left(\tilde{V}(p, \mathcal{P}) \right) \right]$ above $\mathbb{E} \left[U \left(\tilde{V}(p=0, \mathcal{P}=\emptyset) \right) \right]$, because the profit function in equation (2) is increasing in p . Then, $p^* = \bar{p}(\mathcal{P})$ and $M \cdot \mathbf{1}_{\{\mathbb{E}[U(\tilde{V}(p, \mathcal{P}))] \geq \mathbb{E}[U(\tilde{V}(p=0, \mathcal{P}=\emptyset))]\}} = 1$. Define $A_i \doteq (1 - c)V_i^P - V_i^C (\geq 0)$ as the functional surplus that the provider may appropriate should she decide to control touchpoint i , and k the cardinality of \mathcal{P} . Then, equation (3) becomes:

$$\max_{\mathcal{P} \in \mathcal{F}} \Pi(p = \bar{p}(\mathcal{P}), \mathcal{P}) = \frac{kr(1 - \delta)((1 - k)\rho - 1 - \delta(1 + (2n - k - 1)\rho))\sigma_P^2}{2} + \sum_{i \in \mathcal{P}} A_i. \quad (4)$$

Proposition 1 *To determine the best design, the service provider sorts all touchpoints in the decreasing order of A_i , $\forall i \in \mathcal{J}$. Let $A_{[j]}$ indicate the j^{th} element of this ordering. The optimal partitioning of the touchpoints must be of the form $\mathcal{P} = \{[1], [2], \dots, [j] \mid \underline{k} \leq j \leq \bar{k}\}$ and $\mathcal{C} = \mathcal{J} \setminus \mathcal{P}$.*

Proposition 1 outlines an index policy for the touchpoint selection that can be implemented by service providers. The prerequisites for the implementation are the identification and the valuation of the journey touchpoints. The touchpoints can be identified through empathic design techniques (Leonard and Rayport, 1997), whereas their valuation follows marketing techniques like conjoint analysis (Green and Srinivasan, 1990). *Ceteris paribus*, the provider favors touchpoints that i) exhibit low provision cost (low c), ii) offer high functional benefit V_i^P , and/or iii) are challenging for the customer (extremely low V_i^C).

Proposition 2 *The service provider optimally chooses to control k^* number of touchpoints and charge a price p^* , where:*

- I. $k^* = 0$ and $p^* = 0 \forall \sigma_P^2 \geq \bar{\sigma}_P^2$.
- II. $k^* = \left\lfloor \frac{2A_{k^*} - r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2} \right\rfloor = \lfloor \bar{k} \rfloor$ and $p^* = \bar{p}(\lfloor \bar{k} \rfloor) > 0 \forall \sigma_P^2 \in (\underline{\sigma}_P^2, \bar{\sigma}_P^2)$.¹⁰
- III. $k^* = n$ and $p^* = \bar{p}(n) \forall \sigma_P^2 \in (0, \underline{\sigma}_P^2]$.

If the variability of the subjective component is extremely high due to the nature of the service task (i.e., $\sigma_P^2 \geq \bar{\sigma}_P^2$), then no profitable service can be offered. On the other end, for small projected losses due to the variable experience (i.e., σ_P^2 takes values close to $\underline{\sigma}_P^2$), the customer always derives higher value from the provider performing each touchpoint, and the provider controls the entire journey. For the most interesting setting, a careful investigation of Case II reveals that even when $c = 0$ (i.e., $A_i = V_i^P - V_i^C$) the optimal number of touchpoints k^* can acquire interior values, $k^* \in \mathbb{Z}_n \setminus \{0\}$. Thus, the provider foregoes controlling the entire customer journey even when it is costless for her to do so. She does that to avoid the effects of variable customer-provider interactions. Therefore, the decision regarding the extent

¹⁰Through $\lfloor x \rfloor$ we indicate the greatest integer that does not exceed x .

of customer-provider contact cannot follow solely cost or functional benefit considerations. Practical validation for our result can be found in various service environments where the providers offer self-service options (e.g., salad bars in menu-based restaurants) despite the fact that a self-service option may not present significant cost advantages (e.g., the restaurant still employs a significant number of waiters). Figure 2 depicts the provider’s service design in the $\sigma_P^2 \times \rho$ space when the entire customer journey is costless. Next, we try to understand how the interdependencies between

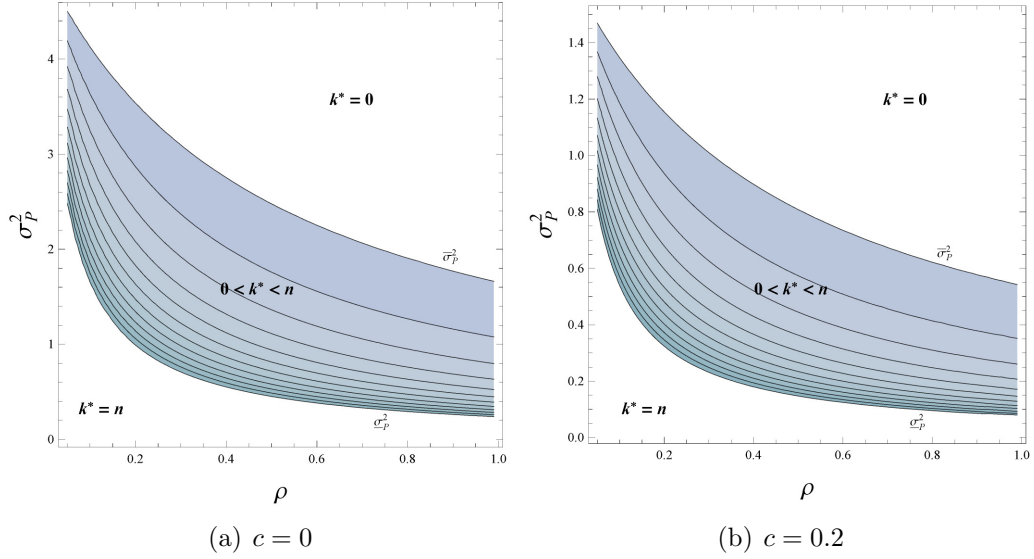


Figure 2: Optimal number of touchpoints in the $\sigma_P^2 \times \rho$ space for $n = 12$, $r = 0.26$, $V_i^P = V^P = 2.28$, $V_i^C = V^C = 1.6$ and $\delta = 0.1$. The “iso-touchpoint” curves are also shown.

the service tasks (i.e., correlated experiences) affect the design decision. We restrict our attention to moderate variability settings where $\sigma_P^2 \in (\underline{\sigma}_P^2, \bar{\sigma}_P^2)$.

Proposition 3 *The optimal number of steps k^* is non-increasing in ρ , r , n and σ_P^2 . It is also non-increasing in δ only when $\delta \in (0, \frac{n-1}{2n-1})$, $\rho \in (\frac{\delta}{(n-1)(1-2\delta)}, 1)$, and $\sigma_P^2 \in (\frac{2A_{[k^*]}}{r(1-\delta)(1+(n-1)\rho)}, \bar{\sigma}_P^2)$.*

The provider benefits from limited control over the journey in settings with highly interdependent tasks. Increased ρ implies that the non-linear effect of variability becomes more pronounced; potential bad experiences cascade throughout the entire

customer journey. The provider accounts for it by limiting her control k^* . A similar rationale applies when r increases, which is when customers become more averse to experience fluctuations. In this case, even low levels of uncertainty σ_P^2 drive higher losses. The effects of the customer journey length (n), and the relative variability between the self-service and the provider options (δ) are more involved (Figure 3). We find that in lengthy customer journeys (i.e., numerous potential touchpoints) optimality results in fewer touchpoints. This is an indirect effect of the journey length n on the boundaries of the interior solution region, i.e., $(\underline{\sigma}_P^2, \bar{\sigma}_P^2)$. As n increases $\underline{\sigma}_P^2$ and $\bar{\sigma}_P^2$ decrease. This happens because the combined loss effect of the variability and interdependencies is magnified. As n increases there are more steps over which the negative experiences may propagate, making it harder to appropriate any benefit even from fewer touchpoints. With respect to the relative variability in the idiosyncratic experience component, the non-monotonic result rests again upon two drivers: first, as δ increases the self-service option becomes less attractive (higher variability); second, given the interdependencies, a higher δ increases the variability effects disproportionately. As such the customer considers not entering the service system. The only potential counter-action from the provider is to control more touchpoints in an attempt to supply functional benefit (V_i^P) to the customer.

2.4.2 Service Design Under Information Asymmetry

In this section we analyze the design decisions of the provider in the presence of asymmetric information. Recall, that the provider's design decisions are interpreted as signals $\mathbf{m}(\theta)$ of her capability θ to deliver high service experiences. We should emphasize here that the subsequent analysis does not assume a competitive setting where both types of providers are present; instead, we consider a monopolistic setting, where consumers do not know the type of the provider. In this context, the *threat* is the fact that customers can attribute positive likelihood to the provider being a

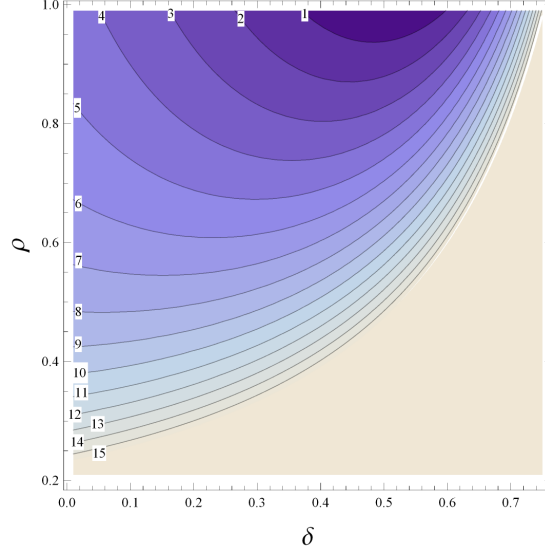


Figure 3: Optimal number of touchpoints in the $\rho \times \delta$ space, for $n = 16$, $r = 0.47$, $V_i^P = V^P = 8.5$, $V_i^C = V^C = 3.67$, $c = 0.3$ and $\sigma_P^2 = 1.3$.

low capability one, when she is of high capability. From a technical standpoint, we make the following conventions that allow much more tractability. First we assume that the experience superiority of a capable provider is broken down as follows. The functional benefit the customer may appropriate in each touchpoint is constant and capability independent i.e., $V_i^\theta = V_i^P$, $\forall i \in \mathcal{J}$ and $\theta \in \{H, L\}$. This assumption allows us to keep the derivations sanely tractable. Still, customers derive an additional **overall** experience V^E benefit when the service is performed by the capable provider. Given the assumed uniformity of the touchpoints, the set \mathcal{P}_θ can be described by its cardinality k^θ (i.e., the number of touchpoints the θ -type provider chooses to control in equilibrium).¹¹ Second, in the analysis of the signaling game we use the real solution \bar{k} as opposed to the integer rounding $\lfloor \bar{k} \rfloor$ (see Proposition 2).¹²

We study the formation of Perfect Bayesian Equilibria (PBE) such that the customers adopt pure strategies. We categorize these equilibria as separating and pooling

¹¹This assumption is without loss of generality; our argument follows through even when $A_i^\theta \neq A_j^\theta$ $\forall i, j \in \mathcal{J}$, i.e., the touchpoint parameters differ and are capability dependent. We offer details in the Appendix.

¹²We further discuss this assumption in the Appendix.

(Bagwell and Riordan, 1991; Stock and Balachander, 2005). In a separating equilibrium, the high-type provider adopts strategies that ensure she cannot be confused with a low-type provider (technically, a low-type provider cannot beneficially mimic those strategies); thus, she successfully signals her capability advantage. In a pooling equilibrium, actions end up being uninformative and customers cannot in equilibrium distinguish between a high and low-type provider. In order to refine the plethora of the resulting equilibria, a characteristic of signaling games, we employ the *intuitive criterion*, as established by Cho and Kreps (1987).

2.4.2.1 Separating Equilibrium.

First, we analyze the existence and structure of the separating equilibria. In a separating equilibrium, the high-type provider adopts a service design that in equilibrium will lead customers to update their prior to the posterior $\phi' = 1$.

Proposition 4 *The high capability service provider can most profitably signal her type by adjusting the number of the touchpoints she controls k^H and charging $p^H = \bar{p}(k^H)$.*

Proposition 4 reveals the relative importance among the two design decisions. It is more beneficial for a provider to signal her type through an informative set of touchpoints as opposed to the price. Then, service price p is adjusted to the maximum value $\bar{p}(k)$ as defined in Lemma 3 in the Appendix.

In order for the high-type provider to successfully signal her capability, she needs to make sure that her design could not be credibly mimicked by a potential low-type provider. That is, a $(p(k^H), k^H)$ design would be a loss-making proposition for a low-type provider compared to the design that would reveal her low type. At the same time, though, a high-type provider should find it profitable to seek separation and not to take an action off the equilibrium path and be perceived as a low-type provider by the customer. In the Appendix we provide the necessary technical conditions for

the existence of such a separating equilibrium.

Proposition 5 *There exists a positive threshold value \hat{V}^E such that for all $V^E \leq \hat{V}^E$ a high-type provider can signal her capability by simply offering her full information optimal design, i.e., she controls $\bar{k}(H)$ touchpoints. The price that the high-type provider charges for the offering is $p^H = \bar{p}(\bar{k}(H)) + V^E$. The threshold \hat{V}^E is defined as follows:*

$$I. \text{ When } c_H < c_L, \text{ then } \hat{V}^E = \frac{(A^L - A^H)(A^L - A^H - r(1-\delta)^2 \rho \sigma_P^2)}{2r\rho(1-\delta)^2 \sigma_P^2} \geq 0.$$

$$II. \text{ When } c_H > c_L, \text{ and } c_H - c_L > \frac{r(1-\delta)^2 \rho \sigma_P^2}{V^P} \text{ then } \hat{V}^E = \frac{(A^L - A^H)(A^L - A^H - r(1-\delta)^2 \rho \sigma_P^2)}{2r\rho(1-\delta)^2 \sigma_P^2} \geq$$

0. In any other case the provider cannot signal her expertise through a full information design choice.

Proposition 5 identifies the most favorable situation for a high-type provider. Under the conditions listed, the customers can extrapolate that a low-type provider would be reluctant to mimick even the full information design choices of the high-type provider. Thus, the high-type provider can successfully signal her type through her full information strategy. Intuitively, the reluctance from a low-type provider arises from the fact that the optimal number of touchpoints $k^*(\theta)$ decreases in c_θ . In Case I, due to the lower costs associated with the provision of a touchpoint, the low-type provider could not have tried to implement $k^*(H)$ unless the premium experience V^E exceeds a threshold \hat{V}^E (see Figure 4). Interestingly, if high experiences are associated with the quality of the service outcome (which can be delivered through higher provision costs, i.e., $c_H > c_L$) as in Case II, then the capable provider can meaningfully signal her type only when her provision cost is large enough, i.e., only when she is an expensive enough expert such as the best specialist doctor. The rationale comes from the fact that a high-type provider can profitably decrease the number of touchpoints she controls *and* avoid being mimicked only for a significantly higher cost c_H . Under that scenario, a potential low-type provider would not choose

in equilibrium to decrease her number of touchpoints. Instead of chasing the relatively small experience premium V^E , she would stick to her full information optimal design lured by her significantly lower cost c_L .

Proposition 6 describes the cases in which a low-type provider has a stronger incentive to mimick the high-type provider's equilibrium actions because of the significant experience premium V^E . In these circumstances, a high-type service provider would adopt a “costly” action and depart from her full information optimal design to signal her capability.

Proposition 6 *For values $V^E > \hat{V}^E$, separation becomes costly for the high-type provider. The following statements characterize the separating equilibrium that satisfies the intuitive criterion.*

I. If $c_H < c_L$, then $k^H = \bar{k}_s(V^E) \geq k^*(H) \forall V^E \in (\hat{V}^E, \hat{V}_n^E)$.

II. If $c_H > c_L$, then $k^H = \underline{k}_s(V^E) \leq k^*(H) \forall V^E \in (\hat{V}^E, \hat{V}_0^E)$.

The price of the service is $p^H = \bar{p}(k^H) + V^E$.

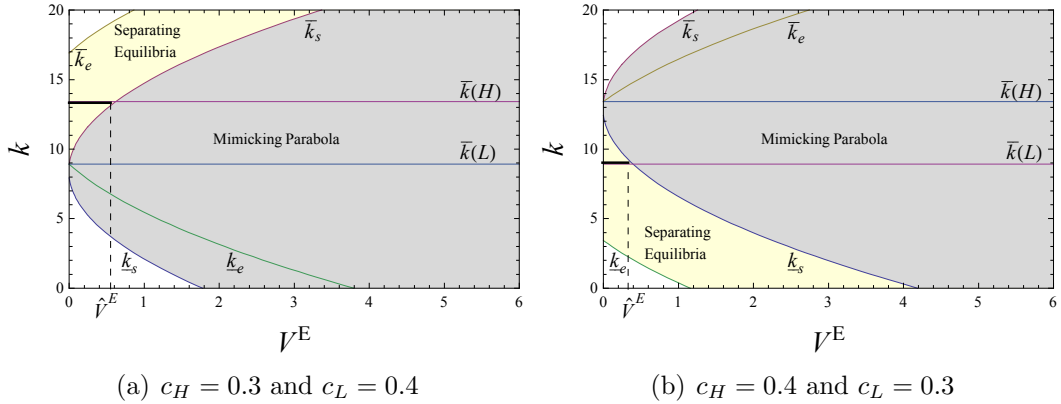


Figure 4: The most favorable (least costly) separation action for a high-type service provider. Type can be successfully signaled through the full information design $\forall V^E \in [0, \hat{V}^E]$ for $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$ and $\rho = 0.46$.

When $V^E > \hat{V}^E$, it is credible in the “eyes” of the customer that a low-type provider profitably mimicks a wider set of high-type action. Depending on the service objective a high-type provider can react to such a threat through two distinctly different service designs. First, when high experiences are associated with streamlined and cost-efficient task completion ($c_H < c_L$), a high-type provider chooses to offer an extended number of touchpoints, i.e., she controls more touchpoints than under a full information benchmark case (Figure 5). Such an offering becomes a rather costly action for a low-type provider to mimick, who would never undertake it and instead would employ her full information optimal design $\bar{k}(L)$. A service design with more touchpoints allows the capable provider to signal her ability to offer a cost-efficient service process. Conversely, if high experiences are associated with the quality level of a costly (expertise-based) service outcome (i.e., $c_H > c_L$), then the capable provider introduces a design with fewer touchpoints than the full information design. In this way, she signals her costly *expertise* to perform the service. The result of Proposition 6 points to a very important managerial implication. New services are often subject to uncertainty regarding the ability of the provider to claim a high experience capability. In such cases, a service provider needs to identify upfront the service objective in order to lay out an informative design. As seen in Figure 5, once V^E exceeds a certain threshold the high-type provider can no longer follow the equilibrium actions prescribed by Proposition 6. The main reason is that, for such high experience premium realized by the consumers, a low-type provider has a very strong incentive to mimick the high-type designs. As a response, a high-type provider implements extreme design configurations (i.e., $k^H = 0$ or $k^H = n$). Proposition 7 prescribes the new set of actions.

Proposition 7 *Under the following conditions, the high-type provider cannot signal her type only through the design configuration.*

- I. If $c_H < c_L$ and $V^E \geq \hat{V}_n^E$, then a separating equilibrium can be reached only if

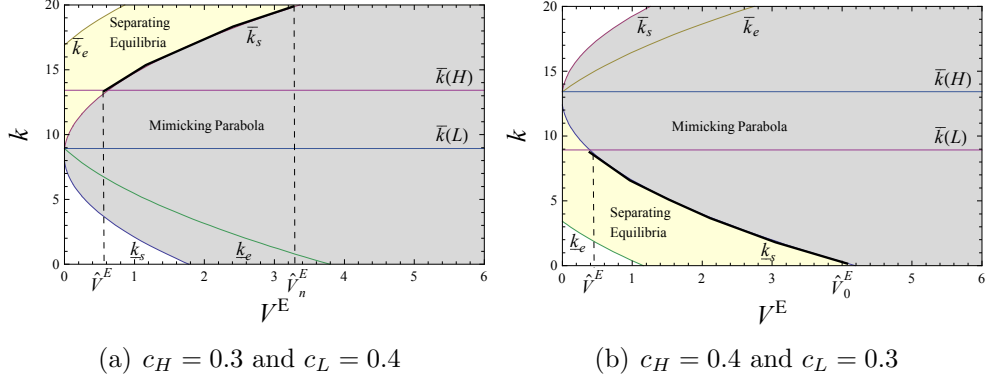


Figure 5: Signaling process efficiency through the control of more touchpoints (on the left) and expertise based outcome through the control of fewer touchpoints (on the right) when $V^E > \hat{V}^E$ and $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$, $\rho = 0.46$.

$$k^H = n \text{ and } p^H = \bar{p}(\bar{k}(L)) + (n - \bar{k}(L))c_L V^P - V^E < \bar{p}(n).$$

II. If $c_H > c_L$ and $V^E \geq \hat{V}_0^E$, no separating equilibrium exists.

In the case of streamlined processes ($c_H < c_L$) a capable provider could potentially satisfy the separation conditions and avoid being mimicked only if $k^H > n$. Clearly, such a design is infeasible. However, Proposition 7 offers an alternative lever to signal capability: the price p^H . A high-type provider can still reap benefits through the costly action of offering a lower price that a potential low-type provider cannot mimic. In expertise-based services the high-type provider is cut out of the market. She cannot credibly signal her type and consumers in equilibrium are not able to tell whether she is of high capability. In that regard, expertise can be signalled through a focused service design up to a limit. Beyond that limit, customers can no longer infer the provider's capability and they act based on their prior belief.

2.4.2.2 Pooling Equilibrium.

Pooling equilibria identify settings in which a high capability provider finds it profitable to choose an action that does not reveal her type. In order for such an action to be an equilibrium action, it shall be that a low type provider has an incentive to

imitate it in equilibrium. In this case the customers' posterior belief ϕ' remains the same as prior one ϕ . In the Appendix we outline the technical conditions for the existence of such uninformative equilibria.

Proposition 8 *A pooling equilibrium exists $\forall \phi \in (0, 1)$ as long as $V^E \geq \hat{V}^E(\phi)$. At equilibrium, the service provider controls $k^P = \bar{k}(H)$ touchpoints and charges the price $p^P = \bar{p}(\bar{k}(H)) + \phi V^E$.¹³*

Proposition 8 reveals that, for a pooling strategy to be an equilibrium strategy, the customers' experience premium needs to exceed a certain threshold. Otherwise, customers would not find it credible that a low-type provider would have an incentive to pool. We show in Figure 6 that a pooling equilibrium exists even when the customers maintain an *a priori* pessimistic view ($\phi = 0.35 < 0.5$) about the provider's capability to offer a high experience. In a pooling equilibrium the service design offered assumes the same touchpoints as in the design of a capable provider under full information $k^P = \bar{k}(H)$.

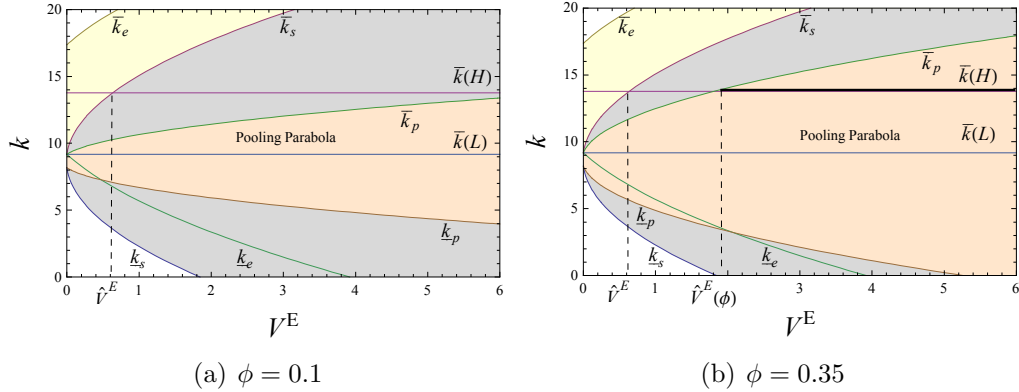


Figure 6: Pooling parabola and the existence of a pooling equilibrium when $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$, $\rho = 0.46$, $c_H = 0.3$, $c_L = 0.4$.

¹³ We can identify cases in which the intuitive criterion fails to further refine the multitude of pooling equilibria. For tractability reasons, we assume that if a pooling equilibrium is formed this will happen where the high type provider can realize the highest payoff. Such equilibrium can also be characterized as focal equilibrium.

Corollary 1 *In the presence of information asymmetry, the high-type provider would optimally design the service offering as follows:*

- I. *If $V^E \in [0, \hat{V}^E]$, then the provider employs the “full-information” service design.*
- II. *If $V^E \in (\hat{V}^E, \hat{V}_n^E]$ ($V^E \in (\hat{V}^E, \hat{V}_0^E]$) and $\phi \geq \bar{\phi}$ ($\phi \geq \check{\phi}$), then the provider chooses an “uninformative” service design, that is, she chooses a pooling strategy. Otherwise, she employs a separating strategy to signal cost efficient (costly expertise) capability.*
- III. *If $V^E > \hat{V}_n^E$ ($V^E > \hat{V}_0^E$) then the provider chooses a pooling strategy unless $\phi < \check{\phi}$ which allows her to signal cost efficiency through the pricing.*

Corollary 1 offers a complete action “map” for the separation or pooling design choices of a high-type provider. We outline conditions that render separation or pooling a beneficial strategy. A pooling strategy is associated with a high enough level of prior belief regarding the provider capability, and a high enough level of the experience premium enjoyed by the customer. We describe the optimal service designs given the level of information asymmetry (ϕ) and the premium V^E for different service objectives (Figure 7).

2.5 Discussion and Directions for Future Research

In this paper, we analyze the design challenges that a service provider faces when introducing an experiential service. We build upon the *customer journey*, a well-grounded representation of a service process, to formalize the service offering as a sequence of distinct steps. At each such touchpoint, a customer forms an experience about the service, which results from both the functional benefit recouped, and the interaction driven component of the service. The overall customer experience is the accumulation of the touchpoint experiences. High experiences depend on the

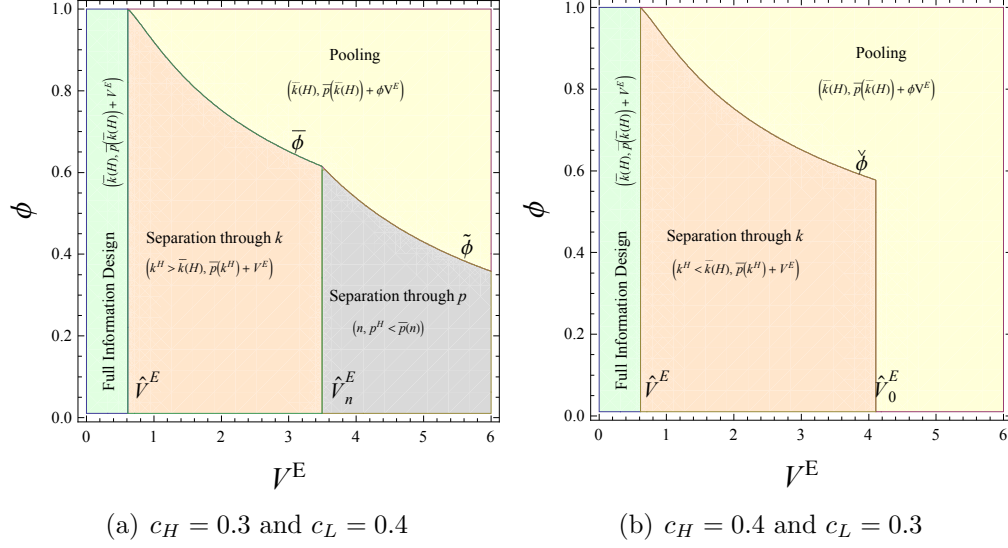


Figure 7: Optimal signaling strategies of the high-type service provider when $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$, $\rho = 0.46$.

objective of a service. For example, customers may associate high experiences with a streamlined service completion, or with the quality of the service outcome. Moreover, in new services, the customer rarely knows with certainty whether the provider is capable of offering a high experience service. A monopolist provider determines her service design through two decisions: the journey touchpoints that she chooses to control, and the price that she charges for the service. We show that service designers may benefit from estimating and understanding the effects of distinct service task parameters: the variability in the experience outcomes realized during the customer-provider interactions, the interdependencies between the tasks performed at the different service touchpoints, and the association between high experience outcomes and the service objective. The insights of our model can be summarized as follows:

- **Which steps of the customer journey should be controlled?** We identify a simple and feasible-to-implement decision rule. The provider orders all the touchpoints in decreasing value of the functional surplus associated with each touchpoint. Then she chooses to control the highest k^* of them, such that the

k^* -th touchpoint balances the functional surplus with the interaction driven experience losses. Our rule is practically appealing because, it relies on existing firm practices: i) the identification of the customer journey (a task that design firms have mastered), and ii) the use of traditional valuation parameters such as the cost c , and the functional benefits V_i^P , and V_i^C , which conjoint techniques in marketing have long analyzed.

- **How much of the service process should be “delegated” to the customer?** When the interaction component of the experience outcome is moderately variable, the optimal number of service touchpoints lies between 0 and n , even when $c = 0$. Thus, the best design configuration cannot be based solely on cost considerations. Instead, indirect “costs” that relate to the interactions between the service provider and the customer may prove significant parameters that determine a service design.
- **Can service design signal capability and how?** Service designs need to account for information asymmetry between the customer and the provider, as they can signal the capability of the provider to offer high experience outcomes. The design implications are not uniform across all settings; instead, they are contingent on the service features that the consumer values in the particular type of service. When a customer associates high experiences with a streamlined, cost-efficient process completion the service design can mitigate information asymmetry through the control of a larger proportion of the customer journey. This signals the ability of the capable provider to efficiently offer and handle more touchpoint interactions with the customer. Instead, when high experiences stem from a costly, expertise-based quality of the service outcome, the provider can benefit by focusing the interaction on the touchpoints that convey her expertise.

The aforementioned insights are based on several assumptions we made during the formulation and analysis of our model. The relaxation of some of these assumptions can offer great future research avenues. Allowing a more dynamic interaction between the provider and the customer, such as the one that may happen when a customer abandons the service process, may potentially change the dynamics of the relationship and the subsequent design implications. For instance, the provider may exert additional effort on specific steps in order to “lure” the customer to stay engaged and commit to a price, or she may reconsider the “location” of the price (i.e., the touchpoint where the customer commits to a price). As an example, consider the practices of providers like Starbucks and Barnes & Noble who invest in costly touchpoints such as the provision of a pleasant lounge area or a comfortable study environment without obliging the consumer to commit to a transaction (e.g., buy a drink or a book, respectively). Moreover, our analysis can be further enriched by accounting for specific behavioral traits such as memory recency effects (Chase and Dasu, 2001; Bitran et al., 2008; Aflaki and Popescu, 2010).

CHAPTER III

TO SELL AND TO PROVIDE?

THE ECONOMIC AND ENVIRONMENTAL IMPLICATIONS OF THE AUTO MANUFACTURER’S INVOLVEMENT IN THE CAR SHARING BUSINESS

3.1 Introduction

Transportation serves an indispensable role in the economy as well as our personal lives, yet it poses a worldwide threat owing to the greenhouse gas (GHG) emissions. Along with increasing global usage of transportation there has been an unsettling surge in GHG emissions. In 2006, the transportation sector accounted for 29% of the total U.S. GHG emissions, realizing a 27% increase from 1990 (U.S. EPA, 2010). Light-duty vehicles accounted for 59% of the total transportation emissions, a 24% increase compared to 1990. This worrisome trend, along with the mandates of the Energy Independence and Security Act of 2007, have spurred policymakers to devise strategies that can reduce transportation emissions (U.S. Department of Transportation, 2010).

In accordance with these efforts, researchers have highlighted the potential role of services as a remedy for the environmental burden caused by human activity (Rothenberg, 2007). Specifically, it has been argued that services can contribute to the “dematerialization” of the economy, which effectively means a reduction in the materials intensity of economic activity (Heiskanen and Jalas, 2000). Along those lines, in recent years manufacturers from various industries have begun to orient their practices towards providing solutions (e.g., mobility, lighting, carpeting) as opposed to strictly

selling their products. This trend, known as *servicization*, reveals the transition from a product ownership economy to a functional or service economy. Servicization is characterized by the emergence of product-based services, also known as Product-Service-Systems (Mont, 2002), which blur the distinction between manufacturing and traditional service activities. Product-Service-Systems (PSS) are business models that extend the traditional functionality of a product by incorporating additional services (Baines et al., 2007). The customer value is linked directly to the “use” rather than the “ownership” of the product. Rolls-Royce’s “power by the hour,” DuPont’s car painting program, and Xerox’s document management solutions are examples of successful PSS (for more examples see White et al., 1999 and Mont, 2004).

In the transportation business and especially in the automotive sector, servicization began with the emergence of car sharing (membership-based) programs. The providers of these programs maintain the control of the assets, which frees the customers from the administrative hassles associated with vehicle ownership. After paying a yearly fee, customers become members of the car sharing program and have access to a large fleet of vehicles. Via internet or telephone, members are able to check vehicle availability and reserve a car in increments as short as one hour and pay only for the time they reserve. Gas, maintenance, and insurance are included in the hourly price. In this manner, car sharing transforms the fixed-costs associated with the ownership of a vehicle (i.e., purchase cost, depreciation, insurance) to variable costs (i.e., usage-related costs).

Zipcar, founded in 1999 and merged with Flexcar in 2008, is the largest for-profit car sharing provider in the U.S. Other major vehicle rental companies like Enterprise Rent-A-Car Co., Hertz Corp., and Avis Budget recently entered the car sharing business (Everson, 2008). Frost & Sullivan (2010) estimates that by 2016 the market in North America will be worth \$3.31B in revenues and will comprise 4.41M members. Interestingly, despite the increasing popularity of car sharing and the promising

projections of growth, auto manufacturers have been reluctant to engage in such business. Only recently has BMW announced their intention to expand the scope of their business by introducing car membership schemes (Fuhrmans, 2010), and Daimler AG operates a car sharing program in only four major cities in the U.S. (CAR2GO, 2011). This hesitation may be attributed to fears of demand cannibalization.

Offering products under membership-based schemes has the potential to attract customers who otherwise would purchase the respective asset (Cervero et al., 2007; Cervero and Tsai, 2004; Lane, 2005). In the ownership (or leasing)¹ case, each consumer is tied to at least one product that he will use to fulfill his mobility needs. However, by entering car sharing programs, customers can derive the same value by using fewer products in total. This phenomenon stems from the fact that the same product can be used by many consumers in different periods of time, resulting in more efficient overall use and less production volume. Additionally, car sharing forces a direct consideration of the driving cost. Making the cost of driving more immediate can compel customers to adopt more efficient driving patterns or even drive less (i.e., the taxi-meter effect, Lambrecht and Skiera, 2006). The U.S. Environmental Protection Agency has categorized car sharing as a top-ten, high-potential, “green-servicizing” business model (U.S. EPA, 2009). Zipcar also claims that every shared car replaces over 15 privately-owned vehicles and that their members drive 5,500 miles or less per year (Zipcar, 2012c); however, such environmental claims have yet to be analytically proven.

The environmental implications of membership programs are still not completely

¹A number of studies (Hawken et al., 2010; Lifset and Lindhqvist, 1999; Fishbein et al., 2000; Agrawal et al., 2012) have assessed the “green” potential of leasing as a business practice. The main question of these studies is whether the manufacturers can (or will) efficiently remarket the used products and extend the effective life of the product. Membership schemes clearly extend the product stewardship idea, which is built in the leasing concept and is used as the main environmental argument by its proponents. However, in our context leasing differs from car sharing in two important aspects that have not been factored in other studies. First, payment is directly linked to vehicle use, which may potentially affect customers’ driving patterns, and second, vehicle production volume may be smaller due to pooling effects.

clear. Membership business can potentially expand the customer base towards segments that previously were inactive. For instance, a car sharing scheme may appear to be attractive to commuters who normally use public transportation modes to cover their mobility needs. In this way, the production volume may increase while the efficiency in use decreases, since the per-user energy consumption or GHG emissions increase. Furthermore, because of the lack of considerable fixed costs, it is possible that customers who previously could afford to purchase a vehicle but then choose to join a car sharing program decide to drive more, thereby increasing the use-related emissions. Therefore, the assessment of the environmental dimension of car sharing schemes is not a trivial subject.

The novelty and increasing popularity of the car sharing programs, along with the the auto manufacturers' hesitation to invest in such programs, motivate us to further explore car sharing business models. In this paper, we study the auto manufacturer's choice regarding whether to provide mobility service (e.g., car sharing) in conjunction with the traditional sales channel. We outline the consumer's choice between purchasing a vehicle, benefiting from the mobility service, or relying on an outside option (e.g., public transportation), and we calculate the effect of each choice on customer's driving pattern (vehicle usage). We identify the conditions under which the auto manufacturer is better off by becoming involved in car sharing. Despite the fact that car sharing has been widely perceived or marketed as an environmentally beneficial business model, we demonstrate that the proliferation of car sharing may actually increase the environmental burden.

The remainder of the paper is structured as follows. In §3.2 we provide a brief review of the literature related to our research. We introduce our assumptions and the basic model in §3.3, while in §3.4 we interpret the optimal decisions of the customers and the manufacturer. In §3.5 we discuss the insights obtained from our results and conclude with directions for future extensions. All proofs and technical details are

provided in the Appendix.

3.2 *Literature*

Our work builds on and contributes to three streams of literature. The first stream comprises studies that aim to support and explain the potential environmental benefits of solution-oriented (servicized) business models. The second stream analyzes pay-per-use schemes, which are typically implemented for information goods and access services. In the third stream, a number of studies empirically identify the main factors that drive consumer demand for car sharing schemes. In the following paragraphs, we provide a brief overview of each of the above research streams, with the objective of positioning our work in the context of the existing literature rather than providing an exhaustive review.

Since its conception, the idea of a functional economy (Stahel, 1994), in which the focus of consumption is not on the products per se but on the services which those products deliver, has been associated with the concept of sustainable development (White et al., 1999). Apart from that association, the literature has also advocated the contribution of functional business models to profitability. It has been proposed that, by focusing on the integrated final customer needs and delivering integrated solutions fulfilling these needs, companies would be able to improve their position in the value chain, enhance the value of their offering, and improve their innovation potential (Wise and Baumgartner, 1999; Sawhney et al., 2003). The concept of Product-Service-Systems has emerged as the natural aftermath of the above stream and has been positioned at the forefront of sustainable development within the framework of a functional economy (Goedkoop, 1999). The definition of PSS varies throughout the literature. However, most authors agree that there exist three different PSS types (U.S. EPA, 2009): i) product-oriented PSS in which a manufacturer, in

addition to selling a product, includes extra services (e.g., after-sales service), ii) use-oriented PSS in which the manufacturer maintains ownership of the product and sells the use or availability of it, and iii) result-oriented PSS in which the manufacturer and the customer agree on a certain result or performance level.

Although identifying an exhaustive typology of PSS is out of the scope of this paper, the above categorization helps us to gain more insight into the thus far vague definition of PSS. Car sharing business models constitute a use-oriented PSS. In their survey paper, Baines et al. (2007) conclude that the literature lacks the analytical rigor necessary for evaluating the environmental and economical dimensions of PSS. They openly call for more quantitative methods, which can help organizations understand the perceived value that potential customers may hold and evaluate the required level of service. Towards this direction, Toffel (2002) discusses the agency problems that arise in such servitized business models, while Kim et al. (2007) and Guajardo et al. (2011) study the implications of performance-based contracting on supply chain relationships and product reliability, respectively. Closer in spirit to our work is the paper of Avci et al. (2012), which studies the adoption and the environmental implications resulting from such adoption of electric vehicles that are offered under a pay-per-use scheme and which can utilize battery switching stations. Their approach, however, does not capture the interplay of production and pricing decisions related to offering vehicles via selling and/or pay-per-use schemes. In this paper we adopt such a holistic approach by incorporating the manufacturer’s perspective. Consequently, we contribute to the growing stream of research that rigorously approaches “servitized” business models, and we jointly assess their environmental as well as economical performance.

Previous research has been prolific in the study of nonlinear pricing schemes for information goods and access services. Like car sharing, business models involving information goods or access services are characterized by two properties: i) no

ownership rights are transferred to the customer and ii) payment is tightly linked to customer use. Varian (2000) proves that sharing can increase the manufacturer's profits when the transactions costs of sharing incurred by customers are smaller than the marginal production cost. Furthermore, when customers have heterogeneous tastes, then the wealthier customers buy and the rest choose to rent. These findings are generalized by Sundararajan (2004) who derives the conditions under which, in the presence of transaction costs, selling and pay-per use schemes should be combined by a monopolist. Balasubramanian et al. (2011) extend this line of work by introducing customer heterogeneity with respect to the frequency of use and the utility per use both in monopolistic and competitive settings. Then, similar to our approach, they study the manufacturer's decision to sell and/or offer pay-per-use. Essegai et al. (2002) investigate the combined effect of customer usage heterogeneity and capacity constraints on the firm's pricing decisions. They find that when capacity is a limiting factor, the customer mix that the firm admits becomes of strategic importance. In this case, the fixed fee is negatively correlated with the usage based fee. On the other hand, when capacity is ample the firm offers unlimited access (i.e., the firm charges only a flat fee). Our work is differentiated with respect to this stream of literature in several important dimensions. Specifically, in our model i) the manufacturer incurs a significant production cost (such cost is typically assumed to be zero in the information goods literature; cf., Jones and Mendelson, 2011), ii) under sharing an increase in the usage of a vehicle inflicts a proportional operating cost on the manufacturer, and iii) customers determine the optimal usage according to their budgetary constraints. Therefore, in our setting the manufacturer's production and pricing decisions cannot be deduced from the insights offered by the existing literature. For instance, by offering car sharing the manufacturer can take advantage of the pooling effect and decrease the total production cost, forfeiting at the same time a higher profit margin. The manufacturer can try to recoup this loss by increasing the usage related fee

which, however, will affect the appeal of car sharing because customers will be forced to drive less.

Despite the fact that car sharing represents a relatively recent innovation in transportation, the increasing popularity of membership schemes has already motivated researchers to investigate the drivers that shape consumer demand for such schemes. The literature has focused on many aspects of car sharing. Prettenthaler and Steininger (1999) use the “total distance” that customers need to travel, the “availability” of the vehicles and “prestige” (i.e., endowment effect, Hanemann, 1991; Shogren et al., 1994) as the most important indicators suggestive of car sharing adoption. Steininger et al. (1996) also suggest the “environmental soundness” of a transportation mode as a determinant of customer adoption. Researchers have also studied the market for car sharing, such as conducting detailed demographic analyses of those who have chosen to join a car sharing service (Burkhardt and Millard-Ball, 2006). Some of the characteristics commonly found among the adopters of car sharing include (Millard-Ball et al., 2005): urban residence, low vehicle ownership, environmental consciousness, propensity to be an “early-adopter,” membership in a small household, high educational background and an age between the 30s and 40s.

The changes in driving patterns after joining car sharing programs have also been the topic of extensive research. After surveying all car sharing members in Austria, Steininger et al. (1996) found that the change in vehicle-miles traveled (VMT) was due to a change in the total distance driven and not the frequency of vehicle use. Specifically, for households that owned a car before joining the membership scheme, the share of trips done via a car for trips of more than 20 km declined significantly. The authors attribute this difference to the fact that cost transparency reveals the advantage of public transportation. On the other hand, Cervero (2003) observes that some car sharing members who previously did not own a car actually increased their VMT. However, the fact that a car sharing membership might deter a future vehicle

purchase should be considered in measuring aggregate VMT impacts. Finally, Shaheen et al. (2004) highlight that despite the increasing interest in car sharing, the efforts of car sharing organizations to evaluate membership impact on travel behavior have been inadequate to characterize long-term effects. Along similar lines, Duncan (2010) calls for research that directly models car sharing adoption. Our paper builds on the observations made by this stream of literature and clearly responds to the call for more elaborate and explicit modeling of the consumer decision making. Through our analysis, we calculate how certain customer characteristics affect the manufacturer’s production and pricing decisions. To the best of our knowledge, this is the first attempt that adopts the auto manufacturer’s perspective and develops a holistic view of the selling and membership business models flourishing in the transportation business.

3.3 *The Model*

In the “business-as-usual” setting the auto manufacturer offers only the option of *Ownership* to the customers (i.e., the manufacturer sells vehicles). The manufacturer’s decisions involve the determination of the selling price F .² For a given time period the selling price F maps directly to an amortized cost of ownership F_O . In our setting the auto manufacturer evaluates the prospect of offering *Membership* (i.e., becoming involved in the car sharing business) in conjunction with *Ownership*. Under car sharing each customer is no longer tied to one car, so the manufacturer has to determine the appropriate number of vehicles S that the car sharing fleet will comprise. The size of the fleet directly affects the probability with which customers find

²The study of possible supply chain coordination issues is out of the scope of this paper. Our work is rather focused on the market conditions under which it would be profitable for the auto manufacturer to become involved in the car sharing business. In the absence of such conditions, the study of supply channel coordination becomes futile. Therefore, in the rest of this paper we choose to ignore the existence of intermediaries (e.g., car dealers).

a vehicle available. Therefore, the manufacturer needs to choose an S that guarantees a minimum service level $\bar{a} \in (0, 1)$, which in the rest of the paper we assume to be industry set. The manufacturer also determines the period (e.g., yearly) fixed membership fee F_M and the per unit of usage fee p_M . Introducing *Membership* in conjunction with *Ownership* has the potential to i) expand the manufacturer's market and attract customers who resorted to alternative modes of transportation (e.g., public transportation) and/or ii) cannibalize on existing vehicle sales. Therefore, the auto manufacturer cannot treat F , S , F_M , and p_M as independent decisions. Figure 8(a) provides a schematic representation of the manufacturer's perspective.

Customers choose a transportation mode $j \in \{O, M, \emptyset\}$ in which O stands for *Ownership*, M for *Membership*, and \emptyset indicates the case in which customers are cut off from the market; that is, they do not cover their transportation needs by *Ownership* or *Membership* but rather rely on an outside option such as public transportation. Without loss of generality, in the rest of the analysis we normalize the costs associated with the \emptyset mode to zero. For any $j \in \{O, M\}$, a customer incurs a period (e.g., yearly) fixed fee F_j , a per unit of usage fee p_j , and a per unit of usage opportunity cost $p_a (\geq p_j)$ when the vehicle is not available. In the case of ownership, the per unit of usage fee p_O equals the exogenously determined gasoline cost. The cost p_a reflects the quality of the alternative modes to which customers resort when the vehicle is not available. For instance, customers who live in cities with an expanded and reliable transportation system incur lower p_a . We assume that under *Ownership* a vehicle will be practically always available, while under *Membership*, the unavailability (probability of shortage) of the vehicle depends on the size S of the fleet, as we have already described. Therefore, from a customer's perspective, the *Ownership* transportation mode can be fully characterized by the vector $\mathbf{O} = (F_O, p_O, 1)$ and the *Membership* mode by the vector $\mathbf{M} = (F_M, p_M, \bar{a})$.

After observing \mathbf{O} and \mathbf{M} , the customer compares his budget y with the the cost

\mathcal{C}_O of covering his mobility needs through *Ownership* and the cost \mathcal{C}_M of covering his mobility needs through *Membership*. Then, for the modes he can afford, he calculates the corresponding utilities \bar{U}_j and chooses the mode that results in the highest utility. If the customer chooses the transportation mode j , then q_j indicates the total time that he decides to use a vehicle for a given time period (e.g., one year). We define usage q_j as the total amount of time a customer needs to keep the vehicle “off-base” (e.g., in a home garage or car sharing parking lot) in order to fulfill his objective (e.g., attend a business meeting or run errands). This time may include both *actual driving* and *idle* time. Through q_j customers must be able to meet their minimum driving requirements d . *Ceteris paribus* customers prefer higher q_j . To avoid unrealistic cases, we introduce \bar{d} to indicate the total amount of time for a given time period that customers would use a vehicle if its usage was costless. Figure 8(b) illustrates the customer’s perspective.

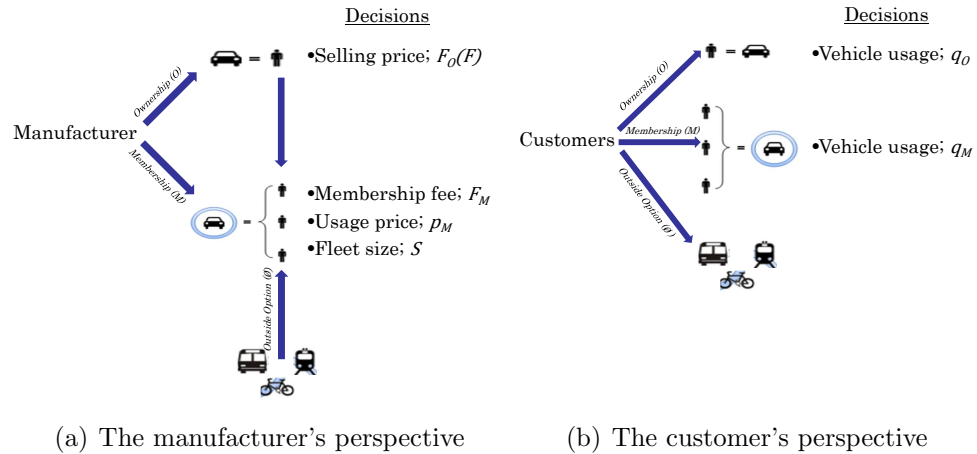


Figure 8: The manufacturer’s and customer’s perspective. If the auto manufacturer introduces *Membership*, then she needs to calculate F , F_M , p_M , and S that can balance the benefit of potential market expansion with the risk of sales cannibalization. The customer first chooses a transportation mode and then, given this choice, decides on the vehicle usage.

In the following sections we formulate the customer’s as well as the manufacturer’s problems by applying backwards induction on the sequence of events delineated in Figure 9. In Table 5 of the Appendix we provide a summary of the notation used

throughout the paper.

3.3.1 Customers' Problem

We consider two homogeneous customer segments based on their transportation needs, H and L (high and low), with sizes n_H and n_L and transportation budgets y_H and y_L , respectively. In this context we use the subscript $i \in \{H, L\}$ to indicate a customer segment rather than an individual customer. For a given transportation mode $j \in \{O, M\}$, each customer of the i segment maximizes:

$$\max_{q_{ij}} \bar{\mathcal{U}}_{ij} = y_i + \mathcal{U}_{ij}(q_{ij}) - \mathcal{C}_j(q_{ij}) \quad (5)$$

$$s.t \ q_{ij} \geq d \quad (6)$$

$$y_i \geq \mathcal{C}_j(q_{ij}) \quad (7)$$

where the utility and cost associated with the use of the vehicle are given, respectively, by:

$$\mathcal{U}_{ij} = \frac{1}{b} \left(\bar{d}q_{ij} - \frac{q_{ij}^2}{2} \right) + \gamma_j \quad (8)$$

$$\mathcal{C}_j(q_{ij}) = F_j + \left(p_j + (p_a - p_j) a_j \right) \omega_j q_{ij}. \quad (9)$$

For similar utility and cost structures refer to Sriram et al. (2011) and Lambrecht et al. (2007).

We use b to indicate the demand slope measuring the change in usage per unit change in price, \bar{d} to represent the baseline usage of mode j when $p_j = 0$, and

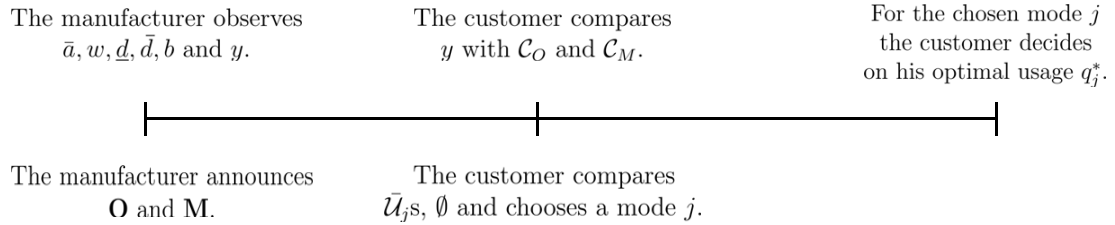


Figure 9: Sequence of events.

γ_j the customers' intrinsic preference to use mode j (e.g., endowment effect in the case of ownership and environmental consciousness in the case of membership). The parameter ω_j indicates the portion of the total usage time q_{ij} that actual driving occurs. Through ω_j we capture the fact that under *Ownership* the driver incurs a cost that stems only from the actual driving time. Conversely, a driver under *Membership* incurs a cost proportional to the total time elapsed between leaving and returning to the point of origin. Therefore, $\omega_O \doteq \omega \in (0, 1)$ and $\omega_M = 1$. The parameter $a_j \in (0, 1)$ captures the availability of a vehicle offered through the j transportation mode. Without loss of generality we assume that under *Ownership*, $a_O = 1$ and for notational parsimony we define $a_M \doteq a = 1 - \bar{a}$.

Constraint (6) ensures that the resulting optimal usage will meet customers' minimum driving needs. The ability of segment i to "participate" in the transportation mode j is ensured through constraint (7). Namely, if (7) holds, then the customers of segment i will be able to afford the use of a vehicle under the mode j for their optimal q_{ij}^* amount of time. If no $j \in \{O, M\}$ can satisfy the constraints (6)&(7), then customers resort to their outside option \emptyset (e.g., public transportation).

Lemma 1 *The customers of the $i \in \{H, L\}$ segment will consider choosing the transportation mode $j \in \{O, M\}$ if and only $F_j \leq y_i - (p_j + (p_a - p_j) a_j) \omega_j d \doteq \bar{F}_{ij}$.*

The necessary condition for the customers of segment i to choose transportation mode j is that the per period fixed fee F_j for mode j does not exceed the threshold \bar{F}_{ij} . It is easy to see that the threshold \bar{F}_{ij} is increasing in the budget y_i and decreasing in p_j, p_a, a_j, ω_j and d . For instance, if a customer's driving pattern involves high driving requirements (d), then this also implies higher driving (use-related) cost. The customer will be able to afford to drive at least d , if and only if F_j is set such that his budget is not exceeded. We should note that Lemma 2 does not *guarantee* the selection of the j mode from the i segment. It rather defines the prerequisite (individual rationality) that needs to be met for customers to consider j as a transportation

option. In the case that a segment can afford participation in both transportation modes, then the choice of the mode will be based solely on the comparison of \bar{U}_{iO} and \bar{U}_{iM} (incentive compatibility).³

The transportation choices of the high and low segments before a possible introduction of *Membership* as a transportation mode can be described by (*Ownership*, *Ownership*), (*Ownership*, \emptyset), or (\emptyset , \emptyset). After the introduction of *Membership*, the manufacturer can lure the high and low segments towards the following seven market configurations: (*Ownership*, *Ownership*), (*Ownership*, *Membership*), (*Membership*, *Membership*), (*Membership*, *Ownership*), (*Ownership*, \emptyset), (*Membership*, \emptyset) and (\emptyset , \emptyset). For each one of these cases to materialize the corresponding individual rationality and incentive compatibility constraints need to hold. For instance, after the introduction of *Membership* the High segment chooses *Ownership* and the Low segment chooses *Membership* (i.e., the case of (*Ownership*, *Membership*) materializes) if and only if constraints (10)-(13) are satisfied.

$$F_O \leq \bar{F}_{HO} = y_H - \omega p_O d \quad (10)$$

$$F_M \leq \bar{F}_{LM} = y_L - (p_M + (p_a - p_M) a) d \quad (11)$$

$$\bar{U}_{HO}^* \geq \bar{U}_{HM}^* \quad (12)$$

$$\bar{U}_{LM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{LO}} \bar{U}_{LO}^* \quad (13)$$

Constraints (10)-(11) and constraints (12)-(13) indicate the individual rationality and incentive compatibility constraints of the high and low segments towards *Ownership* and *Membership*, respectively. If the customers of the low segment cannot afford the *Ownership* transportation mode, then the constraint (13) is reduced to $\bar{U}_{LM}^* \geq 0$ (i.e., the indicator function $\mathbf{1}_{F_O \leq \bar{F}_{LO}} = 0$ if $F_O > \bar{F}_{LO}$; otherwise $\mathbf{1}_{F_O \leq \bar{F}_{LO}} = 1$). Figure 10(c) depicts constraints (10)-(13) in the $F_O \times F_M \times p_M$ space for a given set of parameters. To enhance manuscript readability we exhibit the individual rationality

³If both $\bar{U}_{iO}, \bar{U}_{iM} < 0$ then customers choose \emptyset , i.e., the outside option.

and incentive compatibility constraints for the rest of the six market configurations in the Appendix.

In Figures 11(a)-11(i) we show the materialization of the aforementioned market configurations in the $F_M \times p_M$ space for various values of d and ω . Specifically, we see that for low values of p_M , both segments benefit from the structure of the fixed costs ($F_M < F_O$) and therefore tend to self-select to *Membership*. However, this benefit becomes weaker as p_M increases. Also, as the minimum driving requirement d increases, *Ownership* (and eventually \emptyset) tends to prevail over *Membership*. The reason is that increasing d makes the effect of p_M more pronounced, since under *Membership* customers incur an operating cost for the entire d (active driving and idle time). Reasonably, *Ownership* becomes less attractive to the customers as ω increases. Higher values of ω imply that d comprises higher active driving time. Therefore, besides the higher fixed cost ($F_O > F_M$), customers who choose *Ownership* also incur higher operating cost; hence, they prefer to “migrate” to *Membership*.

The manufacturer needs to identify the most profitable scenario. Therefore, she proceeds by evaluating and comparing the profitability of all seven market configurations. In what follows, we construct the manufacturer’s profit function.

3.3.2 The Manufacturer’s Problem

As shown in equation (14) the calculation of the profit generated from the selling of vehicles to the i segment is straightforward. It involves the selling price F of the vehicles, the marginal production cost c , and the size n_i of the segment i .

$$\Pi_i^O = (F - c)n_i. \quad (14)$$

If the useful life of a vehicle is D time periods and the resale value of it after D is $R = hc$, with $h \in (0, 1)$, then assuming straight line depreciation the selling price F can be expressed as $F = DF_O + hc$, where F_O is the period fixed cost of vehicle

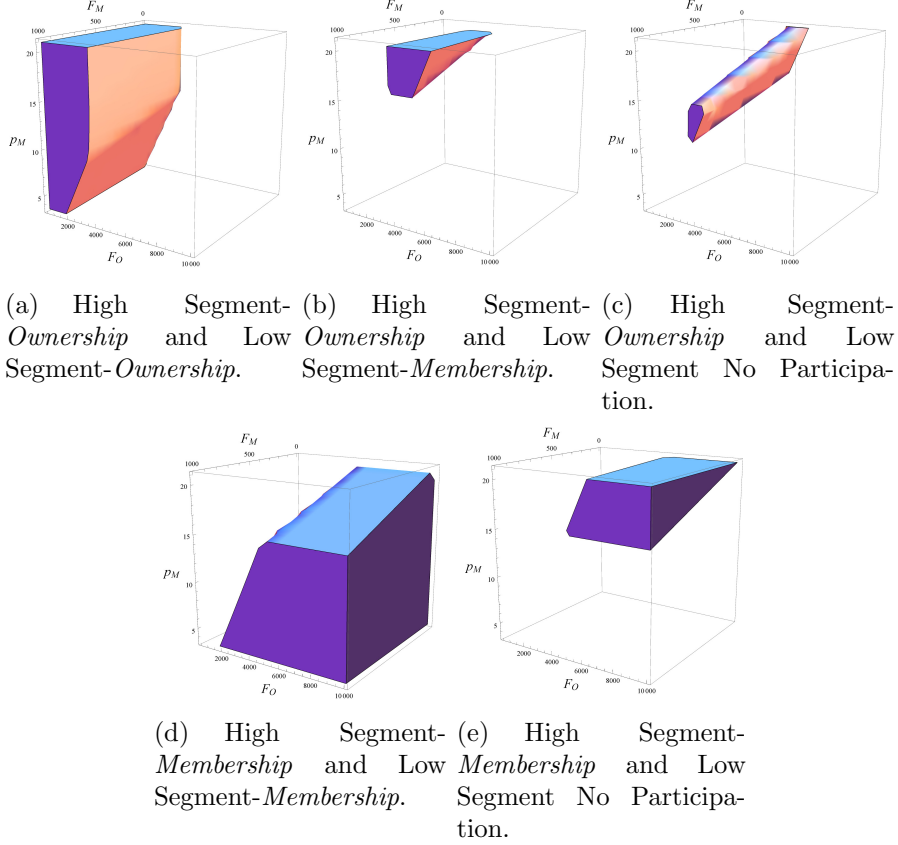


Figure 10: Conditions for the self-selection of segments (H, L) towards *Ownership* (O), *Membership* (M), or *Outside Option* (\emptyset) in the $F_O \times F_M \times p_M$ space (each combination is indicated below the figures). The parameters used are $a = 0.05$, $p_a = 21$, $p_O = 3.5$, $y_H = 8000$, $y_L = 4000$, $\bar{d} = 285$, $\omega = 0.5$, $d = 190$, $b = 1$, and $\gamma_O = \gamma_M = 0$.

ownership that customers incur. Therefore, we can restate equation (14) as follows:

$$\Pi_i^O = (DF_O - (1 - h)c) n_i. \quad (15)$$

The manufacturer faces a more involved reward and cost structure when she operates a car sharing scheme. Specifically, over the useful lifetime D of the vehicles the manufacturer appropriates two streams of revenue. The first stream is generated by the period-fixed subscriptions while the second stream stems from the usage of the vehicles. In this case, however, the manufacturer in addition to the production cost also incurs the operating (i.e., fuel) cost of the vehicles. Regarding the total

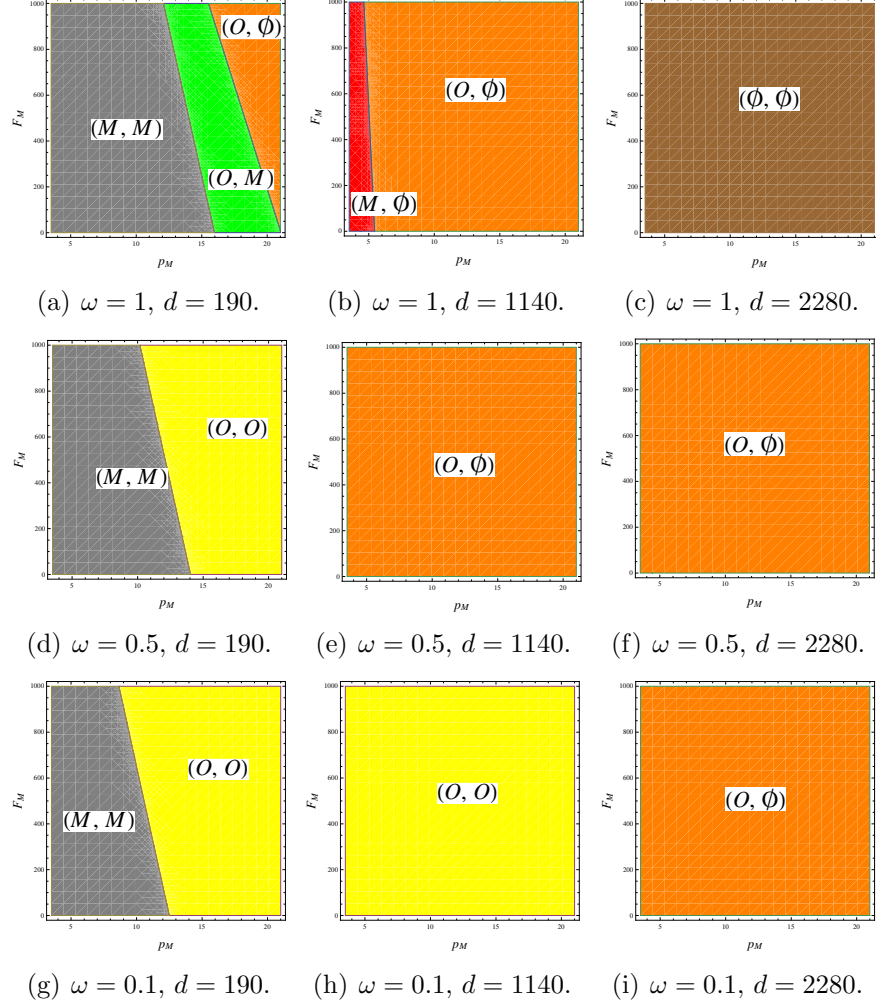


Figure 11: Conditions for the self-selection of segments (H, L) towards *Ownership* (O), *Membership* (M), or *Outside Option* (\emptyset) in the $F_M \times p_M$ space. The parameters used are $a = 0.05$, $p_a = 21$, $p_O = 3.5$, $y_H = 8000$, $y_L = 4000$, $F_O = 3500$, $\bar{d} = 1.5d$, $b = 1$, and $\gamma_O = \gamma_M = 0$.

production cost, it is worth mentioning that the manufacturer can take advantage of the pooling character of car sharing and produce fewer cars. Furthermore, since she maintains ownership of the fleet for the entire useful lifetime D , she can also benefit from the resale value of the vehicles. Thus, the profit generated from providing *Membership* to the i segment is given by

$$\Pi_i^M = n_i D (F_M + (p_M - \omega p_O) \bar{a} q_{iM}^*) - (1 - h) c S. \quad (16)$$

The first term in (16) indicates the profit originating from the subscription fees as

well as the total usage of the vehicles over the D time periods, and the second term is the cost associated with the production and depreciation of the fleet.

The fleet size S determines the pooling character of *Membership*. Specifically, in a typical car sharing scheme customers arrive to one of the designated parking lots where they pick up the vehicle they have chosen, and after the reserved amount of time they return the vehicle to the same parking lot. This description resembles the base stock policy that recoverable spare parts facilities employ. Following the literature on the inventory control of recoverable spare parts (Feeney and Sherbrooke, 1966; Smith, 1977), we model *Membership* as an $(S - 1, S)$ inventory system, in which the base stock level S corresponds to the total number of vehicles in the system. In such systems, a replacement item is ordered upon arrival of each demand. Customers arrive to the system according to Poisson process $\mathbf{N} = \{\mathbf{N}(t) : t \geq 0\}$ with rate $\bar{\lambda}$ (customers per unit of time). The lead-time \mathbf{L} corresponds to each customer's (stochastic) usage duration, and it is distributed according to general probability distribution $\mathbb{G}(\cdot)$ with mean $\bar{\tau}$. In our setting the arrival rate can be expressed as $\bar{\lambda} = n^M \frac{\xi}{T}$, where ξ is the number of times a customer uses a vehicle (i.e., number of trips) during a period of length T and n^M is the total number of customers that choose *Membership* in the given period. The mean “recovery” time (i.e., time until a customer returns the vehicle) is $\bar{\tau} = \frac{q_M^*}{\xi}$ (time per use). If both segments self-select to *Membership*, then $\bar{\tau} = \frac{\left(\frac{n_H}{n_H+n_L}q_{HM}^* + \frac{n_L}{n_H+n_L}q_{LM}^*\right)}{\xi}$. Figure 12 illustrates the operation of our inventory control system.

We also assume that when all cars are occupied by other customers a new customer arriving to the system waits until a car becomes available (i.e., the inventory system works under full backordering). This is a realistic assumption, given that in practice i) the industry-set service level \bar{a} is relatively high and ii) customers can reserve in advance and make the appropriate adjustments in their schedule if a car is not available at the desired time. The customers factor into their calculations the fact that

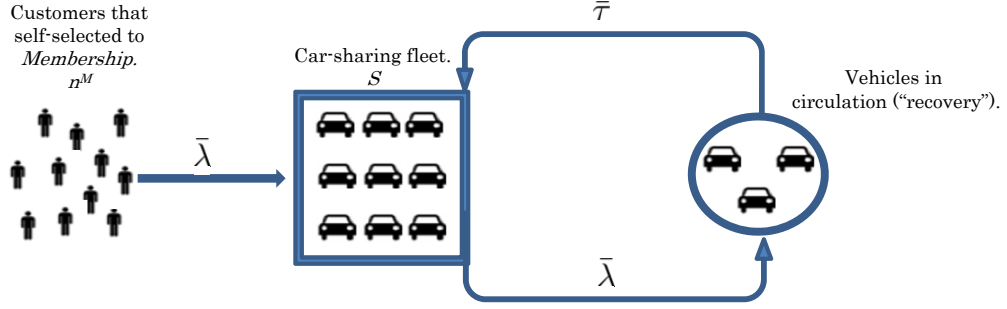


Figure 12: *Membership* as an inventory control system.

a fraction a of their requests will be backordered (i.e., they will have to wait/reschedule or visit a different parking lot) through the cost p_a , which then can be viewed as the provider's backordering cost.

Under the aforementioned assumptions, the inventory system is an ample capacity ($M/G/\infty$) queueing system; therefore, from Palm's theorem, the steady state probability that s vehicles are occupied (i.e., in circulation) can be given by the Poisson distribution with rate Λ ,

$$\mathbb{P}[s; \Lambda] = \frac{e^{-\Lambda} \Lambda^s}{s!} \quad (17)$$

where $\Lambda = \bar{\lambda} \bar{\tau} = \frac{q_M^* n^M}{T}$ is the workload of the system. For large enough values of customer population, Λ becomes sufficiently large; therefore, we can approximate the Poisson distribution with a normal distribution of mean and variance Λ and c.d.f $\Phi(k)$ (Zipkin, 1998).⁴ Under *Membership*, the manufacturer needs to guarantee at least an \bar{a} service level. She can achieve that by choosing an S such that the constraint (18) is satisfied.

$$\bar{a} = 1 - a \leq \Phi(S). \quad (18)$$

However, the manufacturer has no incentive to exceed \bar{a} ; therefore, it is straightforward to show that at optimality she chooses $S^* = \Lambda + z_{\bar{a}} \sqrt{\Lambda}$ which we can expand to

⁴For large enough customer population we can also ignore possible state dependency issues attributed to the closed-loop type of the car-sharing schemes; see Figure 12.

(19)

$$S^* = \frac{q_M^* n^M}{T} + z_{\bar{a}} \sqrt{\frac{q_M^* n^M}{T}} \quad (19)$$

where $z_{\bar{a}}$ indicates the standard normal z value corresponding to the service level \bar{a} . Having introduced Π_i^O and Π_i^M we can fully characterize the manufacturer's maximization problem for each possible market configuration. For instance, after the introduction of *Membership* the manufacturer can calculate the optimal values F_O^* , F_M^* , p_M^* that induce the High segment to choose *Ownership* and the Low segment to choose *Membership* by maximizing

$$\max_{F_O, F_M, p_M \geq 0} \Pi = (F_O D - (1 - h)c) n_H + n_L D (F_M + (p_M - \omega p_O) \bar{a} q_{LM}^*) - (1 - h) c S$$

$$s.t \quad S = \left(\frac{q_{LM}^* n_L}{T} + z_{\bar{a}} \sqrt{\frac{q_{LM}^* n_L}{T}} \right)$$

$$F_O \leq y_H - \omega p_O d$$

$$F_M \leq y_L - (p_M + (p_a - p_M) a) d$$

$$\bar{U}_{HO}^* \geq \bar{U}_{HM}^*$$

$$\bar{U}_{LM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{LO}} \bar{U}_{LO}^*.$$

The manufacturer's maximization problems for the rest of the market configurations are shown in the Appendix.

3.4 Analysis

In this section we solve and interpret the results from both the customer's and the manufacturer's problems. Conditional on the customer's ability to participate in (afford) the j mode, the customer's problem entails the determination of the optimal usage q_{ij}^* . The manufacturer factors in the customers' decisions and then determines the optimal \mathbf{O} and \mathbf{M} that can result in the materialization of the most profitable market configuration.

3.4.1 Customer's Problem

In what follows we characterize customers' usage decisions in isolation from the manufacturer's decisions. That is, at this point \mathbf{O} and \mathbf{M} are treated as given.

Proposition 1 *If the customers of segment i were to participate in transportation mode j , then at optimality they would use a vehicle for $q_{ij}^* = \min \left\{ \max \{ \tilde{q}_{ij}, d \}, \bar{q}_{ij} \right\} = \min \left\{ \max \{ \bar{d} - b(p_j + (p_a - p_j)a_j)\omega_j, d \}, \frac{y_i - F_j}{(p_j + (p_a - p_j)a_j)\omega_j} \right\}$ amount of time.*

It is straightforward to see that q_{ij}^* is nondecreasing in d , \bar{d} , y_i and nonincreasing in p_j , p_a , b and ω_j . For instance, as we can see in Figure 14, q_{iM}^* decreases as p_M increases. Reasonably, customers would use a vehicle less as the hourly reservation fee becomes greater. It is more insightful, however, to contrast the q_{iM}^* , as it varies with p_M , to q_{iO}^* . Specifically, from Figure 14 we see that for greater values of p_M customers would decide to use a vehicle under *Membership* less compared to a vehicle under *Ownership*. This is attributed to the use-related costs of *Membership*. Namely, as such costs increase customers are forced to adjust their vehicle usage and possibly resort to more efficient driving patterns (e.g., avoid discretionary trips). This behavior is in accordance with the claims made by car sharing providers that customers tend to drive less after joining a car sharing program. However, Propositions 2 and 3 identify conditions under which such claims can be challenged. Under these conditions, a customer who migrates from *Ownership* to *Membership* may actually increase the environmental burden caused by higher GHG transportation emissions.

Proposition 2 *If $p_M > \hat{p}_M$, then a value \bar{y} exists such that the vehicle usage under *Membership* is higher than the vehicle usage under *Ownership* for all $y < \bar{y}$.*

As we can see in Figure 13 above a certain level of y , customers can afford both transportation modes. For moderate values of y customers tend to use a vehicle more under *Membership* as opposed to under *Ownership*. Vehicle usage is limited under

Ownership because of the high fixed cost F_O (i.e., customers are left with limited surplus after paying F_O). This effect is reversed as the budget y increases. For higher budget values, customers realize higher surplus that they can then spend on vehicle usage up to \bar{d} . The same customers are forced to choose $q_{iM}^* < q_{iO}^*$ because vehicle usage is “penalized” more under *Membership* (higher p_M and p_a).

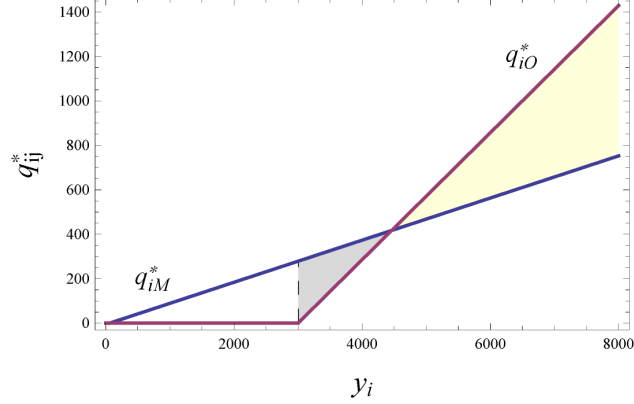


Figure 13: Optimal vehicle usage with respect to the budget y_i . The parameters used are $a = 0.05$, $p_a = 21$, $p_O = 7$, $F_O = 3000$, $F_M = 60$, $p_M = 10$, $\bar{d} = 1710$, $d = 0$, $b = 1$, $w = 0.5$, and $\gamma_O = \gamma_M = 0$.

Proposition 3 *Under the following cases a value \bar{p}_M exists such that the vehicle usage under Membership is be higher than the vehicle usage under Ownership for all $p_M < \bar{p}_M$.*

- I. $\bar{d} - abp_a < d < \frac{y_i - F_M}{ap_a}$ and $q_{iO}^* < d$.
- II. $d < \bar{d} - abp_a < \frac{y_i - F_M}{ap_a}$ and $q_{iO}^* < \bar{d} - abp_a$.
- III. $\frac{y_i - F_M}{ap_a} < \max \{d, \bar{d} - abp_a\}$ and $q_{iO}^* < \frac{y_i - F_M}{ap_a}$.

Interestingly, in Figure 14 we see that for smaller values of p_M (which are still higher than the gas cost p_O), customers selecting *Membership* tend to use a vehicle more than the customers under *Ownership*. The rationale behind this observation arises from the fact that, because of the decreasing variable (usage-related) cost p_M

and the lower fixed *Membership* cost (at least as observed in practice; see Zipcar, 2012d) F_M , customers realize a higher (monetary) surplus that they consume by using the vehicle more.⁵

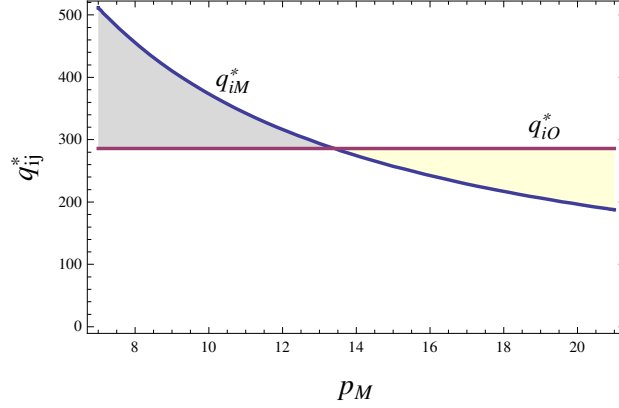


Figure 14: Optimal vehicle usage with respect to the price p_M . The parameters used are $a = 0.05$, $p_a = 21$, $p_O = 7$, $y_i = 4000$, $F_O = 3000$, $F_M = 60$, $\bar{d} = 1710$, $d = 0$, $b = 1$, $w = 0.5$, and $\gamma_O = \gamma_M = 0$.

Propositions 2 and 3 support our initial claim that the assessment of the environmental character of car sharing programs is not a trivial subject. Although car sharing has received wide support from both NGOs and government agencies as an environmentally beneficial business model (U.S. EPA, 2009), our findings call for caution because they indicate that it is possible for such business models to cause an increase in the environmental burden.⁶

However, for the assessment of car sharing's environmental implications to be complete, the changes in vehicle use need to be evaluated in conjunction with the

⁵Customers benefit from higher vehicle usage since \bar{U}_{ij} is increasing in q_{ij} .

⁶The side effects of increased vehicle usage can be mitigated if the car sharing fleet comprises environmentally friendly vehicles (e.g., hybrids, electric vehicles). However, such vehicles tend to be more expensive, in this way affecting the manufacturer's decision to include them in the fleet. Therefore, this case merits further investigation, which we conduct in a future extension of this paper (i.e., in the rest of the paper we assume that the manufacturer offers only conventional vehicles). In 2009, car sharing fleets comprised 87% conventional vehicles. Frost & Sullivan (2010) estimates that, by 2016, conventional vehicles with internal combustion engines will still dominate the car sharing market with a 60% share.

manufacturer's optimal pricing and production decisions. Such decisions will determine the segments' self-selection and provide us with a clear picture of both the resulting production volume and vehicle usage. In the next section we characterize the manufacturer's decisions.

3.4.2 Manufacturer's Problem

Before the introduction of *Membership* as a transportation mode, the manufacturer has two options: i) sell only to the high segment or ii) sell to both segments. Lemma 3 characterizes the manufacturer's decisions.

Lemma 2 *Prior to the introduction of Membership the manufacturer finds it optimal to sell to both segments if and only if $n_L > \tilde{n}_L$ and $y_L > \tilde{y}_L$. In this case, she optimally sets $F_O = \bar{F}_{LO}$.*

In deciding whether to sell to both segments, the manufacturer needs to balance the trade-off between lower a profit margin and a higher sales volume. The manufacturer can recoup the loss in the profit margin only when the size of the low segment exceeds the threshold \tilde{n}_L . In this case, she has no incentive to allow for surplus in the low segment's budget; therefore, she sets $F_O = \bar{F}_{LO}$. The requirement $y_L > \tilde{y}_L$ ensures that the low segment's budget is sufficient to guarantee a positive margin for the manufacturer. In the rest of the analysis, we use the manufacturer's optimal decisions and profitability prior to the introduction of *Membership* as our benchmark scenario.

The manufacturer's optimization problem entails the determination of the optimal F_O , p_M , F_M , and S . With respect, to the pricing decisions p_M and F_M , it is easy to show that different combinations of (p_M, F_M) can result in the same profit for the manufacturer. Therefore, in order to avoid unrealistic solutions, we remove one "degree of freedom" from the manufacturer by determining the membership fee, F_M , exogenously. A survey of the membership fees found in practice reveals, that F_M

contributes or subtracts a rather trivial amount to the manufacturer’s profit or customers’ transportation budget, respectively. The number of decision variables, and the sequential nature of the manufacturer’s decision making process render the analytical derivation of insights challenging. For that reason we conduct a full factorial experimental design for the parameters of the manufacturer’s problem and through numerical optimization we generate a large population of optimal solutions. In what follows, we provide the different parameter values we used for our factorial experiment.

Motivated by the results obtained from surveys (Millard-Ball et al., 2005; Cervero et al., 2007) regarding the travel characteristics of car sharing members we assume that customers’ driving patterns can be categorized under four different profiles that are uniquely characterized by the values of d and ω . Before we describe the approach we adopted in order to estimate d and ω , we need to remind the reader that, in our setting, vehicle usage is defined as the total amount of time that a customer reserves or keeps the vehicle “*off-base*.” *Actual* driving may occur only for a *part* of this time, which we capture through the parameter ω . From Santos et al. (2011) we borrow Table 1, which shows the average annual vehicle miles traveled per household. Based

Table 1: Average annual vehicle miles per household.

Income	Number of Vehicles				
	0	1	2	3	4+
< \$25k	530	8,430	1,551	22,490	34,444
\$25k-\$50k	1,871	10,089	20,625	26,583	41,383
\$50k-\$75k	3,160	12,008	23,381	33,126	44,279
\$75k+	2,792	13,706	27,579	37,146	47,015

on Table 1 and assuming an average driving speed of 30 miles/hour (this is a typical assumption in transportation studies; see Frost & Sullivan, 2010; Santos et al., 2011), we construct Table 2, which indicates the average annual vehicle (actual) driving hours per household. The values in Table 2 vary from as low as 18 hours to as high as 1576 hours.

Table 2: Average annual vehicle driving hours per household.

Income	Number of Vehicles				
	0	1	2	3	4+
< \$25k	18	281	52	750	1148
\$25k-\$50k	62	336	688	886	1379
\$50k-\$75k	105	400	779	1104	1476
\$75k+	93	457	919	1238	1567

Table 2 can provide useful estimations only if its values are combined with values of ω . Regarding the estimation of ω , it is useful to investigate the different purposes for which customers use their vehicles. Most transportation studies (e.g., Millard-Ball et al., 2005; Cervero et al., 2007; Santos et al., 2011) identify four major trip purposes: i) Shopping/Buying Groceries ii) Recreational/Social Activities iii) Traveling To-From Work/Work-Related Activities, and iv) Personal Business. It is true that a customer can be involved into a mixture of these types of activities, and that a market can include a mix of such customers. However, in pursuance of basic insights, we use “pure” scenarios where a *single, distinct* profile exists in the market and we appose the results. Specifically, in order to shed light on how different driving patterns affect the manufacturer’s as well as customers’ decisions, we categorize the aforementioned trip purposes under the following four distinct profiles.

Profile 1 : *Shopping/Buying Groceries*, under which $d = 190$ hours/year ($\approx 1/2$ hours/day) and $\omega = 1$. Typical activities under this profile would include daily errands (e.g., going to the super market, or dry cleaner), which are usually performed in an efficient and expeditious manner.

Profile 2 : *Recreational/Social Activities*, under which $d = 1140$ hours/year (≈ 3 hours/day) and $\omega = 0.5$. Although such activities may not take place daily, upon occurrence they may require considerable amount of time, only a part of which may involve actual driving (e.g., helping a friend move, or taking a short trip on the 4th of July).

Profile 3 : *Traveling To-From Work/Work-Related Activities*, under which $d = 2280$ hours/year (≈ 9 hours/day; assuming 250 *working* days in a calendar year) and $\omega = 0.1$. This profile captures cases in which a vehicle is mainly used to commute to and from someone's workplace.

Profile 4 : *Personal Business*, under which $d = 2280$ hours/year (≈ 9 hours/day; assuming 250 *working* days in a calendar year) and $\omega = 0.5$. The difference between Profile 3 and Profile 4 is that the amount of time that actual driving occurs is higher under Profile 4. This can describe settings in which vehicle use is related to the operation and/or development of someone's personal business (e.g., solicitation of potential customers or consultation of existing customers with on site visits).

The set $(d, \omega) = \{(190, 1), (1140, 0.5), (2280, 0.1), (2280, 0.5)\}$ represents Profiles 1-4 compactly. This set also corresponds to $(d\omega) = \{190, 570, 228, 1140\}$ actual driving hours and is representative of the range of values calculated in Table 2. Although the typology of the profiles we devised is by no means exhaustive, we should highlight that Profiles 1-4 should be seen in juxtaposition to each other. Namely, it is the relative values of d and ω that shape the definition of Profiles 1-4 and which can potentially induce different manufacturer and customer decisions.

Table 3 summarizes the values we use for all of our parameters, which form 104,976 numerical instances (i.e., unique numerical combinations). The length of a time period is considered to be one year which comprises $T = 8760$ hours and, therefore, prices and vehicle usage are expressed on a yearly basis (\$/hour and hours/year respectively). In the Appendix we provide a thorough explanation of the methods we employed to estimate our parameters.

In the rest of the analysis we proceed to the numerical optimization of the manufacturer's profit for each possible market configuration (*Cases 1-7*) and we identify

Table 3: Summary of the parameters used in the numerical optimization.

Description	Symbol	Values
Vehicle Useful Life	D	5 years
Vehicle Production Cost	c	$\{\$15 \times 10^3, \$22.5 \times 10^3, \$25 \times 10^3\}$
% of the Vehicle Production Cost Retained after D years	h	$\{0.3, 0.4, 0.5\}$
Vehicle Operating Cost	p_O	$\{4, 6.5, 9\}$ \$/hour
Cost of not Finding a Vehicle Available	p_a	$\{69.80\omega, 81.46\omega, 104.6\omega\}$ \$/hour
Demand Slope	b	$\{15, 25, 35\}$ hours/\$
Transportation Budget	(y_H, y_L)	$\{(\$5.525 \times 10^3, \$3.90 \times 10^3), (\$8.125 \times 10^3, \$5.525 \times 10^3), (\$11.375 \times 10^3, \$8.125 \times 10^3)\}$
Customer Population	(n_H, n_L)	$\{(2.807 \times 10^3, 1.951 \times 10^3), (2.193 \times 10^3, 3.049 \times 10^3)\}$
Annual Membership Fee	F_M	$\{\$50, \$150, \$250\}$
Service Level	\bar{a}	$\{90\%, 95\%, 98\%\}$
Driving Profile	(d, ω)	$\{(190, 1), (1140, 0.5), (2280, 0.1), (2280, 0.5)\}$
Maximum Usage Requirements	d	$\{1.5d, 2d\}$ hours/year
Intrinsic Preference to Own/Be a Member	(γ_O, γ_M)	$(0, 0)$

the most profitable one. We are interested in the implications of the manufacturer's decisions on profitability, consumer surplus, and environmental burden.

3.4.2.1 Implications on Profitability

A potential involvement of the auto manufacturer in the car sharing business can affect her profit through a number of different mechanisms. Specifically, by introducing *Membership*, the manufacturer may be able to enjoy a decrease in total production cost due to the pooling effect of car sharing. Additionally, the manufacturer may be able to expand her market by allowing customers who previously could not afford *Ownership* to use *Membership* as their transportation mode. On the other hand, by offering *Membership* the manufacturer becomes vulnerable to sales cannibalization. The manufacturer can mitigate the cannibalization effect through the pricing decisions F_O and p_M . However, given the fact that under *Membership* vehicle usage not only constitutes a source of revenue but also a cost for the manufacturer (since she is responsible for the operating cost of the vehicles), it is unclear how the prices F_O and p_M will affect the usage decisions of the customers. *Ceteris paribus*, customers derive higher utility under a transportation mode that allows them larger vehicle usage. In order to gradually build our understanding of the drivers that shape the manufacturer's profit, we start by studying the segments' self-selection towards the transportation modes.

Observation 1 *On average, the manufacturer achieves higher market expansion when customers' driving patterns fall under Profile 1 or Profile 3. On the contrary, if the customers' driving patterns fall under Profile 4, then the manufacturer does not realize any changes in the composition of the customer base.*

In Figure 15(a) we observe that market coverage is more extensive under Profile 1 and Profile 3 and it decreases under Profile 2 and Profile 4 (i.e., more instances of $DNDN$ are realized). This is consistent with the $d\omega$ values of the profiles. Higher values of $d\omega$ imply that customers' minimum vehicle usage requirements (minimum actual driving time) are costlier, which can increase the number of instances in which the transportation budget is rendered insufficient.

We also see that *Membership* prevails in Profiles 1 & 3. Once more, these profiles are characterized by small $d\omega$. Therefore, by switching to *Membership*, customers of these profiles are freed from the high fixed cost of *Ownership* and can actually derive more utility by increasing their vehicle usage. For that exact reason, as shown in Figure 15(b), market expansion occurs more often under Profiles 1 & 3. Market expansion under Profile 1 is realized in fewer instances than under Profile 3, because under Profile 1 market coverage before the introduction of *Membership* is at its highest. In contrast to Profiles 1 & 3 we do not observe many instances of *Membership* under Profile 2. In this profile, customers have higher $d\omega$; therefore, the manufacturer cannot profitably lure them to choose *Membership*. This is more pronounced under Profile 4, under which no instances of *Membership* are observed. It is also apparent from Figure 15(a) that the introduction of *Membership* not only creates new demand but also cannibalizes the sales of vehicles. For instance, consider in Profile 1 the transition from (O, DN) (i.e., the high segment chooses *Ownership* and the low segment does not participate) to (M, M) (both the high and the low segments choose *Membership*). The fact that the manufacturer induces such cannibalization can be attributed to the pooling effect of car sharing (i.e., the same number of customers

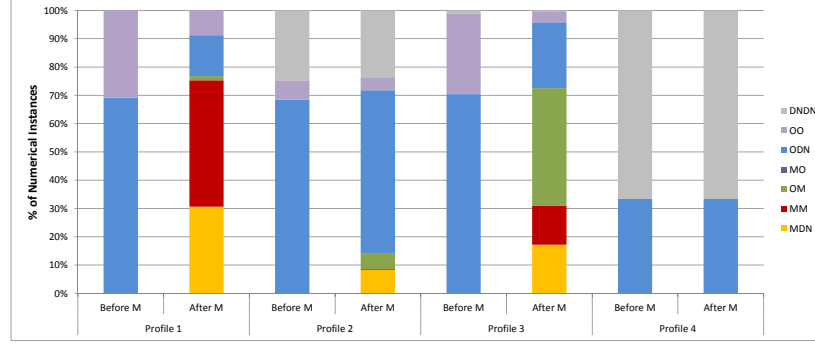
can be served with fewer vehicles), through which she can possibly fully recoup the losses generated by the demand cannibalization.

Further investigating the composition of each profile, we see that Profile 2 has more instances of *Ownership* compared to Profile 1. The reason is that Profile 3 is characterized by smaller $\omega = 0.1$, which renders the option of *Ownership* appealing to customers due to its smaller variable cost (under *Membership* the variable cost is higher because of the manufacturer markup; furthermore, customers are exposed to the p_a cost of not finding a vehicle available). That is, despite the existence of *Membership*, customers may still be able to affordably meet or even exceed their minimum usage requirements d under *Ownership*. We continue our analysis by describing the levers that the manufacturer uses in order to induce the changes in the composition of the customer base.

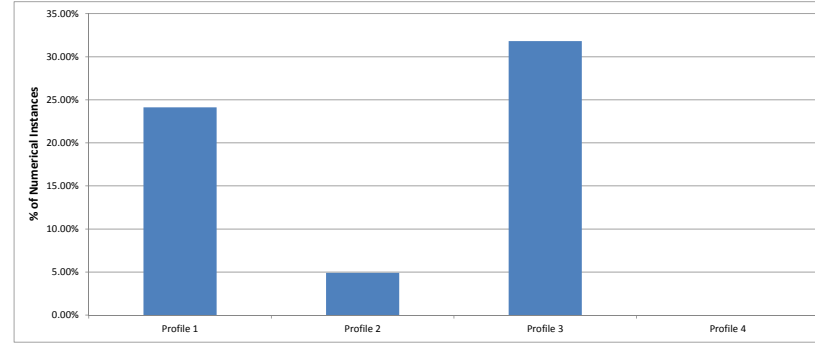
Observation 2 *Before the introduction of Membership, the manufacturer on average charges the highest selling price under Profile 1 and next under Profile 3. After the introduction of Membership the highest selling occurs at its maximum under Profile 3. On average, the highest hourly rate is realized under Profile 1 and it decreases with respect to the rest of the profiles.*

As we can see in Figure 16(a), before the introduction of *Membership* the vehicle selling price is consistent with the minimum actual driving requirements $d\omega$ of each profile. For instance, Profile 4 is accompanied by the maximum $d\omega = 1140$ hours; therefore, the manufacturer charges the lowest F_O in order to stimulate demand for vehicles. Similarly, the highest price is offered under Profile 1. Given the small $d\omega$ of Profile 1 and the lack of transportation alternatives, it is easier for the manufacturer to extract a larger part of customers surplus by charging a higher price and still allow them to meet their usage requirements.

After the introduction of *Membership* the selling price is the highest under Profile 3. For reasons explained earlier, *Ownership* constitutes an attractive transportation



(a) Optimal segmentation before and after the introduction of *Membership*.



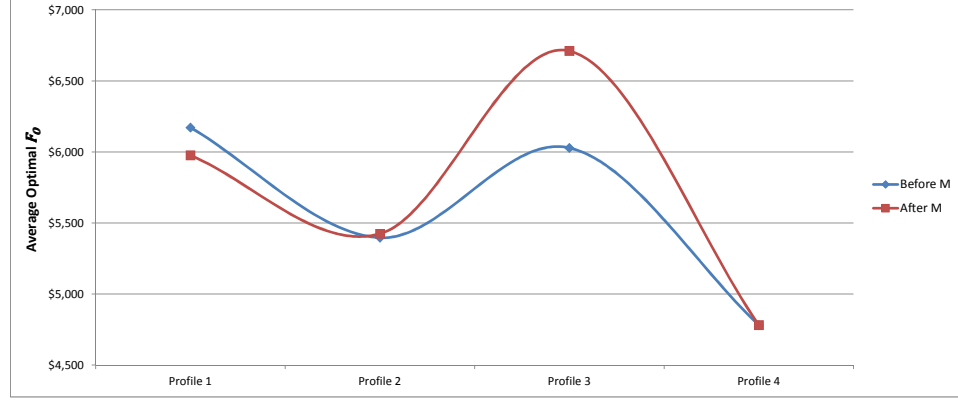
(b) Market expansion after the introduction of *Membership*.

Figure 15: The segments' self-selection before and after the introduction of *Membership*. *O* indicates *Ownership*, *M* indicates *Membership* and *DN* indicates no participation. For instance, (O, DN) means that the high segments chooses *Ownership* and the low segment relies on the outside option (i.e., cannot afford *Ownership* or *Membership*). Each profile is associated with different customer driving patterns. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

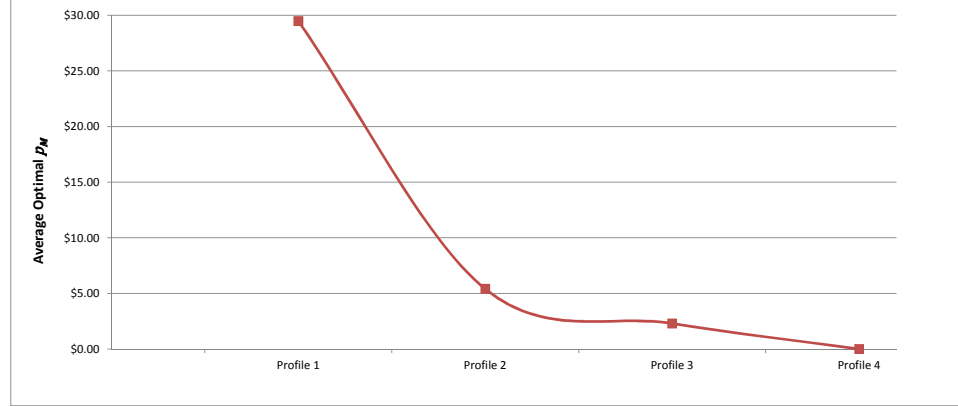
option for customers of Profile 3. Therefore, the manufacturer increases the selling price F_O in order to increase the appeal of *Membership*, through which she can potentially enjoy a decrease in the total production cost due to the pooling effect. The large $d\omega$ of Profile 2 does not allow the manufacturer price flexibility.

In Figure 16(b) we also find that the hourly rates are in accordance with the ranking of ω across profiles. That is, since under *Membership* the manufacturer is responsible for the operating cost p_O , higher values of ω imply higher rates p_M . The hourly rate appears to be particularly high under Profile 1, because the small $d\omega$

allows the manufacturer to extract customer surplus without losses in the demand. In what follows we examine how the aforementioned pricing strategies and the resulting changes in the composition of the customer base affect the manufacturer's profitability.



(a) Annualized average optimal vehicle selling price before and after the introduction of *Membership*.



(b) Average optimal hourly rate of *Membership*.

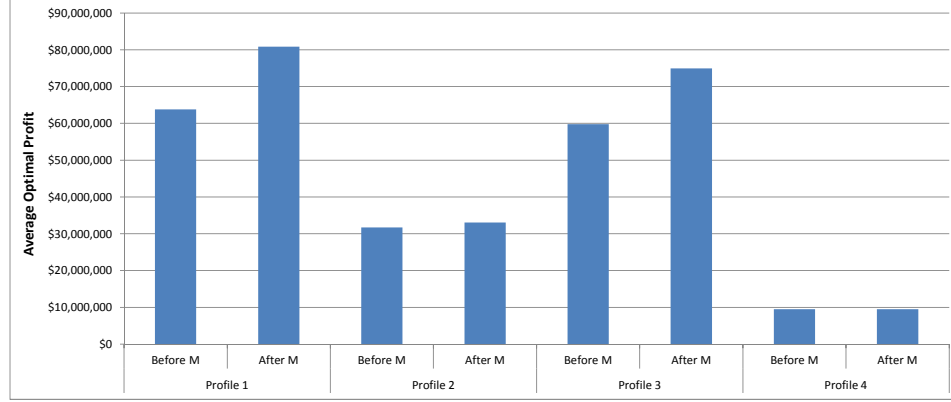
Figure 16: The auto manufacturer's optimal pricing strategies before and after the introduction of *Membership*. Each profile is associated with different customer driving patterns. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

Observation 3 *The manufacturer is on average better off by offering car sharing in conjunction with the traditional selling of vehicles. The manufacturer benefits the most when customers' driving patterns fall under Profile 1.*

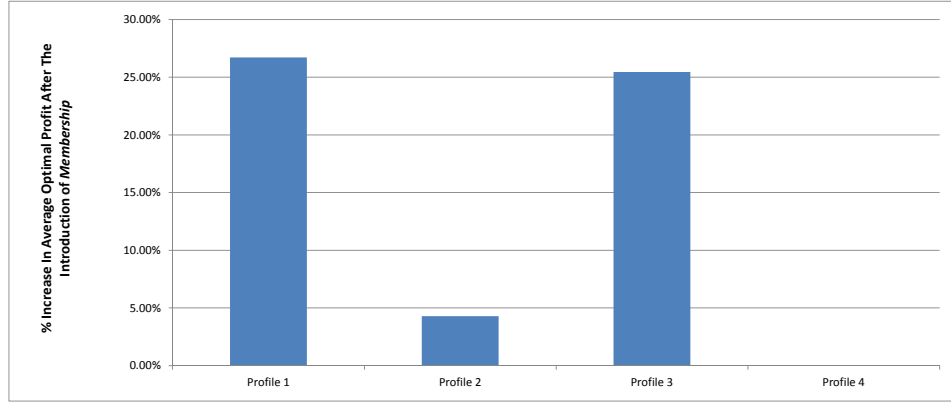
We examine the manufacturer’s profitability before and after the introduction of *Membership* as a transportation alternative. As it can be seen in Figure 17(a), prior to the introduction of *Membership* the manufacturer is able to achieve the highest profit when customers’ driving patterns fall first under Profile 1, then Profile 3, Profile 2, and last Profile 4. This observation is consistent with the extent of market coverage observed in Figure 15(a) for the various profiles. In Figure 17(b) we see that the manufacturer benefits from the introduction of *Membership* under Profiles 1-3 while she realizes no change under Profile 4. The largest percent increase in the manufacturer’s average profit occurs under the profiles in which *Membership* prevails (i.e., Profile 1 and Profile 3). The percent change in the manufacturer’s average profit maintains the same ordering with respect to the profiles as the average profit before the introduction of *Membership*. The benefit to the manufacturer under Profile 1 is slightly larger than under Profile 3 because in the latter more instances of *Ownership* materialize (Figure 15(a)).

These observations can provide clear guidance to the manufacturer regarding her dilemma on whether to become involved in the car sharing business. If customers’ driving patterns are characterized by Profile 1 or Profile 3, we find strong evidence that the manufacturer will benefit from such involvement. Profile 2 offers small benefits that in practice may not outweigh the capital cost (e.g., investment in IT infrastructure, long-term leasing of parking locations; Hart et al., 2005) that the manufacturer incurs when she creates a car sharing network. Our findings also strongly suggest that when customers’ driving patterns fall under Profile 4, a potential involvement of the auto manufacturer in car sharing will be at best futile.

Observation 3 establishes the benefit in profit that the manufacturer (especially under Profile 1 or Profile 3) can derive by offering mobility solutions in conjunction with the traditional sales channel. However, such a benefit can comprise an increase in the revenue and/or a decrease in the total production cost. The increase in the



(a) Average optimal profit before and after the introduction of *Membership*.



(b) % Increase in the average optimal profit after the introduction of *Membership*.

Figure 17: The manufacturer’s average optimal profit for different driving patterns before and after the introduction of *Membership*. Each profile is associated with different customer driving patterns. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

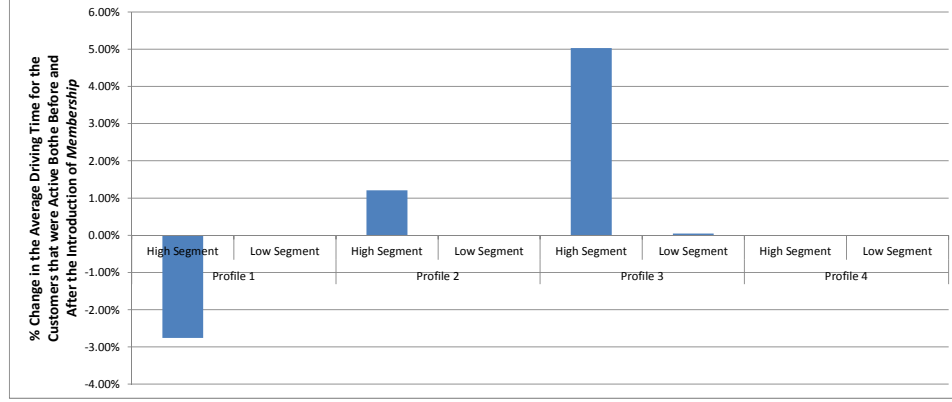
revenue may potentially stem from an increase in the total vehicle usage, either due to market expansion (i.e., customers who before the introduction of *Membership* could not afford *Ownership*, they can now afford *Membership*) and/or an increase in the vehicle usage from customers that are active both before and after the introduction of *Membership* (e.g., consider the increase in driving that a customer, who before the introduction of *Membership* chooses *Ownership*, may commit when freed by the fixed cost F_O after *Membership* is offered). The decrease in the total production cost can be attributed to the pooling effect of car sharing. Therefore, in order to disentangle the

main forces that shape the manufacturer's profit increase, we need to investigate how vehicle usage and production volume change after the introduction of *Membership*.

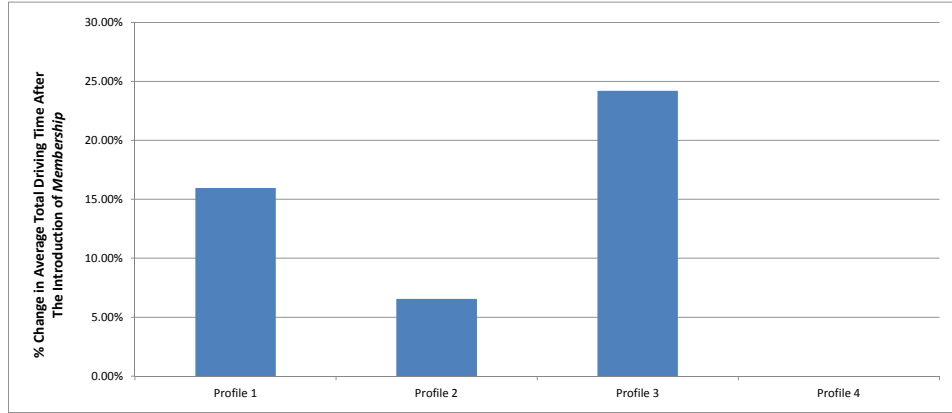
Observation 4 *After the introduction of Membership the average driving time increases under Profile 1, Profile 2, and Profile 3 while it remains the same under Profile 4. The highest increase occurs under Profile 3 and Profile 1. The increase in total driving time is primarily attributed to the market expansion achieved by the manufacturer after the introduction of Membership.*

Figure 18(a) illustrates how customers who were active both before and after the introduction of *Membership* adjust their driving time after *Membership* is offered. The decrease in the driving time under Profile 1 is consistent with our previous explanation regarding the manufacturer's ability to extract customer surplus and the high hourly rate we observed in Figure 16(b). We also see that customers of the High segment of Profile 3 increase their actual driving time because they benefit from lower hourly rates. However, Figure 18(a) needs to be studied in conjunction with Figure 18(b) in which we show the percent change in the total driving time. Specifically, in Figure 18(b) we see that the change in the actual driving time is in accordance with the market expansion observed in Figure 15(b). Combining the findings of Figures 18(a) and 18(b) we conclude that the overall increase in the total driving time after the introduction of *Membership* can be mainly attributed to the market expansion effect. It is worth mentioning that our finding regarding the change in the driving time of the High segment of Profile 1, offers support to Zipcar's claim that after becoming members, their customers reduce the total amount of time they drive. However, this claim does not universally hold for all of our driving profiles.

Observation 5 *After the introduction of Membership the production volume on average decreases under Profile 1, Profile 2, and Profile 3 while it remains the same under Profile 4. The highest decrease is realized under Profile 1 and Profile 3.*



(a) % Change in the average optimal driving time of the customers who were active both before and after the introduction of *Membership*.



(b) Percent change in the average optimal total driving time after the introduction of *Membership*.

Figure 18: Change in the average optimal driving times for different driving patterns before and after the introduction of *Membership*. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

The percent change in the average total number of vehicles produced, shown in Figure 19, is in accordance with the number of *Membership* instances found in Figure 15(a). Namely, the pooling effect is strongest under Profile 1, while it decreases under Profile 3 due to the higher number of *Ownership* instances that Profile 3 comprises. Observations 4 and 5 give rise to Corollary 2.

Corollary 2 *The benefit to the manufacturer after the introduction of Membership stems i) mainly from the pooling effect under Profile 1, ii) from the revenue increase*

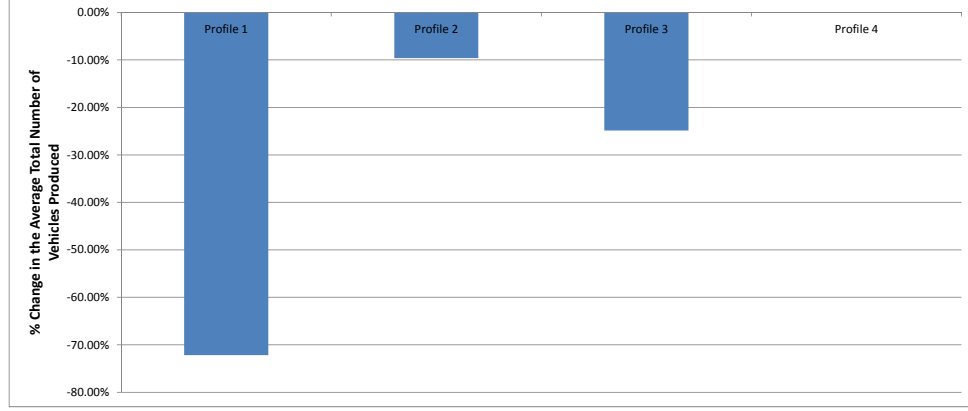


Figure 19: Percent change in the average production volume after the introduction of *Membership*. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

(due to market expansion) to a greater extent and the pooling effect to a lesser extent under Profile 2, and iii) evenly from the revenue increase and the pooling effect under Profile 3.

It has already been shown that Profiles 1 and 3 are the most appealing to the manufacturer. However, the factors that drive the increase in profit vary across the different profiles. In particular, as we can see in Figure 20, pooling is the dominant effect under Profile 1 due to the prevalence of *Membership*. Revenue contribution in Profile 1 is limited due to the higher p_M (see Figure 16(b)) and the low driving requirements, $d\omega = 190$. In Profile 3 the contributions of the revenue increase and cost decrease are almost equal. The reason is found in the fact that, although under Profile 3 we have observed many *Membership* instances (see Figure 15(a)), and therefore we would expect the pooling effect to dominate, we have also found that the total driving time increases the most (see Figure 18(b)), which results in an equally strong contribution to the manufacturer's profit increase. Under Profile 2, the fewer instances of *Membership* limit the effect of pooling, allowing the contribution from the revenue increase associated with the higher driving times to be larger.

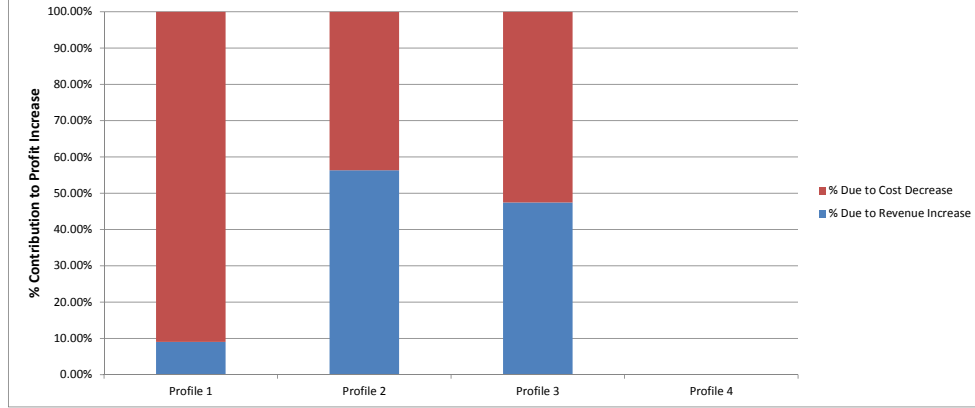


Figure 20: Percent of the manufacturer’s profit increase attributed to revenue increase and cost decrease along with a detailed breakdown of the revenue. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

3.4.2.2 Implications on Consumer Surplus

Given the aforementioned changes in the customer base composition and total driving time, we are interested in investigating how the consumer surplus, $\bar{\mathcal{U}}_{ij}$, is affected. Changes in the consumer surplus may originate from changes i) in the number of customers that become active after the introduction of *Membership* (i.e., customers who could not afford *Ownership*, and who become active by choosing *Membership*), ii) in the total driving time that affect the utility, $\mathcal{U}_{ij}(q_{ij})$, that customers derive and/or, iii) in the monetary surplus, $y_i - \mathcal{C}_j(q_{ij})$, that customers appropriate.

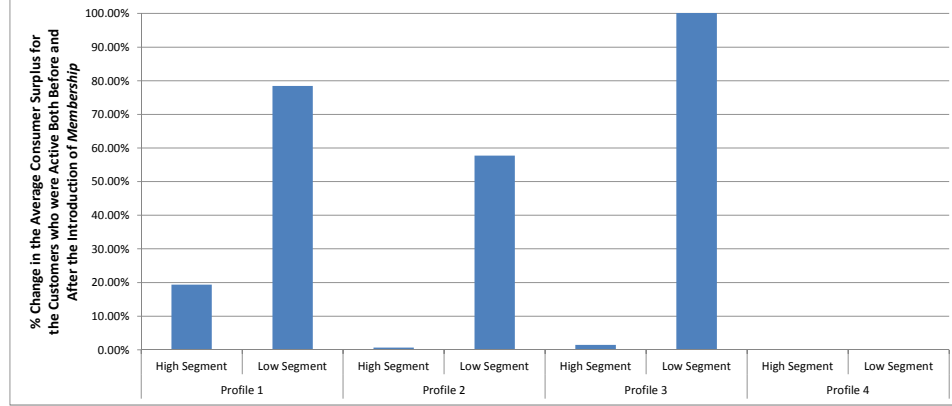
Observation 6 *After the introduction of Membership the average consumer surplus increases when customers’ driving patterns fall under Profile 1, Profile 2, or Profile 3, while it remains unchanged under Profile 4. The largest increase happens under Profile 1. The change in the surplus can be attributed to the market expansion effect. The Low segment appears to benefit the most from the introduction of Membership.*

Observation 6 reveals the harmony between manufacturer profitability and consumer surplus. Namely, under Profiles 1-3 both the manufacturer and the customers benefit from the introduction of *Membership*. Figures 21(a) and 21(b) can help us

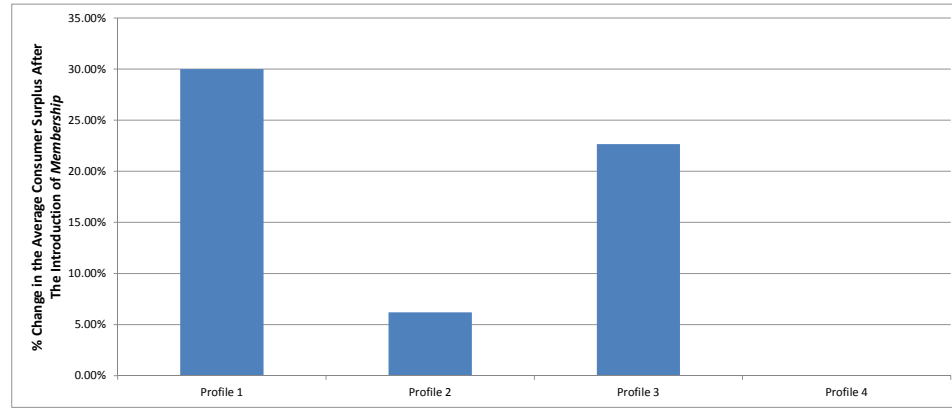
enhance our understanding about the drivers of the consumer surplus increase. Specifically, in Figure 21(a) we see that the surplus of the customers who were active both before and after the introduction of *Membership* increases under Profiles 1-3. The customers of the Low segment appear to benefit the most from the introduction of *Membership* as they realize the largest increase in the surplus. In Figure 18(a), we have seen that the Low segment after the introduction of *Membership* does not change its driving time. Therefore, we can safely conclude that the significant increase in the surplus of the Low segment we observe in Figure 21(a) stems exclusively from the monetary surplus that customers can enjoy while being able to meet their minimum vehicle usage requirements.⁷ Especially for the High segment of Profile 1, we see that after the introduction of *Membership* the consumer surplus increases by 20% even though the driving time decreases.

As expected, in Figure 21(b) we see that the overall consumer surplus increases. However, the magnitude of the increase shown in Figure 21(b) is smaller than the magnitude observed in Figure 21(a). The reason is that Figure 21(b) also incorporates the cases in which customers before the introduction of *Membership* could not afford *Ownership*. After *Membership* is offered, these customers benefit from becoming active. However, the manufacturer's pricing is probably set such that it allows these customers to meet their minimum usage requirements, d , but at the same time exhausts their transportation budget (i.e., not allowing for monetary surplus). Overall, the highest surplus increase happens under Profile 1 because of the large number of *Membership* instances already observed in Figure 15(a).

⁷This effect is more pronounced for the Low segment of Profile 3. Customers of this profile are characterized by relatively small $d\omega$ and small $\omega = 0.1$, which in compliance with the small p_M found in Figure 16(b), result in high monetary surplus when customers are freed from the fixed cost of *Ownership*.



(a) % Change in the average consumer surplus of the customers who were active both before and after the introduction of *Membership*.



(b) Percent change in the consumer surplus after the introduction of *Membership*.

Figure 21: Change in the average consumer surplus for different driving patterns before and after the introduction of *Membership*. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

3.4.2.3 Implications on Environmental Burden

We now divert our attention to the environmental implications of the manufacturer's decision to offer car sharing by calculating the change in the total environmental burden after the introduction of *Membership*. The total environmental burden comprises the CO₂ emissions generated during the production phase and the CO₂ emissions generated during the usage phase of vehicle. According to Honda (2012), Toyota (2012), and Ford (2012), in 2010 the vehicle production of i) Honda resulted in 755 kg CO₂ per vehicle produced, ii) Toyota resulted in 900 kg CO₂ per vehicle produced, and iii)

Ford resulted in 1,010 kg CO₂ per vehicle produced, respectively. We calculate the average of these reported emissions to be 888.33 kg CO₂ per vehicle produced and we allocate it uniformly over the service life expectancy of a vehicle which we assume to be 10 years (Kobayashi, 1997). Hence, we arrive at 88.83 kg CO₂ per vehicle produced. With respect to the vehicle usage phase, we estimate estimate 0.31 kg CO₂ per mile by using the industry average 29.20 MPG (Honda, 2012) along with assuming 8.92 kg CO₂/gallon (U.S. EPA, 2012) and an average driving speed of 30 miles/hour. We combine this information with our findings regarding the total production volume and the total driving time⁸ and we make Observation 7.

Observation 7 *After the introduction of Membership the average environmental burden increases when customers' driving patterns fall under Profile 1, Profile 2, or Profile 3, while it remains unchanged under Profile 4. The largest increase materializes under Profile 3.*

Figure 22 demonstrates that for the profiles under which the manufacturer realizes a profit increase, the environmental burden also increases. This reveals an underlying tension between manufacturer profitability and environmental sustainability. Specifically, the largest increase in the environmental burden occurs under Profile 3 which is also characterized by the largest increase in profit (Figure 17(b)). It is straightforward to establish that the overall increase in the environmental burden is due to the pervasive market expansion effect. For instance, although we have seen that under Profile 1 the decrease in the production volume is rather substantial (almost 75% decrease; see Figure 19), this decrease is not sufficient to counterbalance the environmental implications of the increase in total driving time due to the expansion of the customer

⁸In the previous section, for the sake of expositional parsimony we did not provide the results about the total driving time and total production volume before or after the introduction of *Membership*. Instead, we illustrated the corresponding percent changes (Figures 18(a), 18(b), and 19). The results about the total driving time and total production volume are readily available from the authors upon request.

base. This is more pronounced when customers' driving patterns fall under Profile 3 because in this case the pooling effect is weaker (smaller decrease in the production volume) while the increase in the total driving time is stronger. The limited market expansion observed in Profile 2 also limits the increase in the environmental burden.

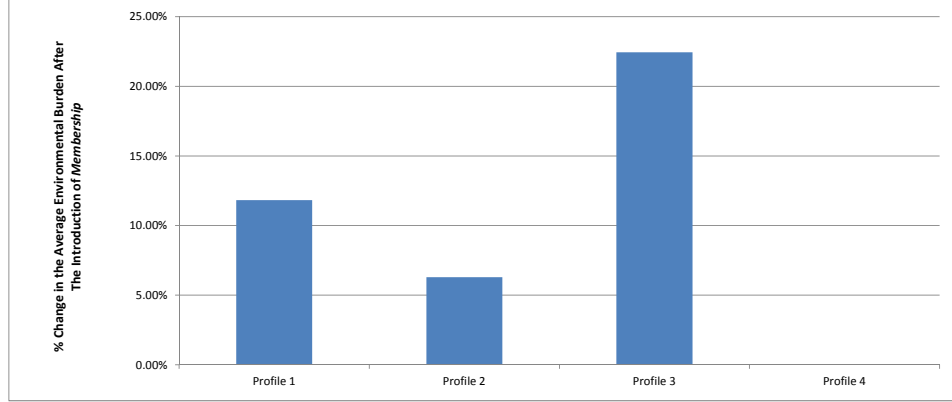


Figure 22: Percent change in the environmental burden after the introduction of *Membership*. Profile 1 indicates $d = 190$ and $\omega = 1$, Profile 2 indicates $d = 1140$ and $\omega = 0.5$, Profile 3 indicates $d = 2280$ and $\omega = 0.1$, and Profile 4 indicates $d = 2280$ and $\omega = 0.5$.

Our findings in Observation 7 and Figure 22 are in direct contrast with the claims in favor of the environmental character of car sharing. However, we need to caution the reader that it has been assumed that the environmental burden caused by the outside option \emptyset , is negligible. This may not always hold true (e.g., the outside option may comprise other less energy efficient transportation modes like taxi cabs), in which case the environmental implications of the market expansion effect may be relatively less pronounced. Furthermore, car sharing may offer additional collateral benefits which we have not quantified in our analysis. For instance, such benefits include the decrease in the need for parking spaces or the facilitation of customers to use public transportation (e.g., many car sharing parking lots are conveniently locate near metro stations). Therefore, our analysis may be considered a worst case environmental scenario providing an upper bound for the environmental burden.

3.4.2.4 Sensitivity Analysis

In this section we want to identify how and to what extent our problem parameters affect the manufacturer’s benefit from becoming involved in the car sharing business. Towards this end, we use Global Sensitivity Analysis (Wagner, 1995; Souza et al., 2004; Subramanian et al., 2011), which involves the regression of the performance metric of interest (i.e., in our case the percent change in the manufacturer’s profit after the introduction of *Membership*) on the problem parameters. Table 4 shows the output of the multiple regression. The column of the standardized beta coefficients reveals the relative importance of the different parameters. Namely, higher absolute values of the standardized beta coefficients indicate a stronger effect of the corresponding parameters on the manufacturer’s benefit.

Table 4: Regression output (Global Sensitivity Analysis). The “percent change in manufacturer’s profit” after the introduction of *Membership* serves as the dependent variable.

Parameter	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Constant	1.094	0.026		42.450	0.000
y_H	-0.001	0.000	-2.471	-57.946	0.000
y_L	0.001	0.000	2.212	51.889	0.000
w	0.665	0.018	0.370	37.065	0.000
p_a	-0.005	0.000	-0.337	-56.948	0.000
a	-4.287	0.047	-0.268	-91.831	0.000
c	3.43×10^{-5}	0.000	0.225	76.793	0.000
h	-1.610	0.023	-0.201	-68.698	0.000
p_O	0.037	0.001	0.115	38.440	0.000
n_L	6.530×10^{-5}	0.000	0.055	18.803	0.000
d	-3.840×10^{-5}	0.000	-0.053	-3.701	0.000
\bar{d}	7.190×10^{-7}	0.000	0.002	0.151	0.880
b	-4.860×10^{-5}	0.000	-0.001	-0.208	0.835

We find that the customers’ transportation budget exerts the strongest influence on the manufacturer’s benefit. Although this may not be surprising at first glance, it is worth highlighting the difference in the direction of this effect depending on whether the budget is associated with the High or Low segment. Specifically, in Table 4 we see that as the transportation budget, y_L , of the Low segment increases, the benefit to the

manufacturer also increases. This is because the manufacturer does not have to price unprofitably low in order to induce customers to choose *Membership*. However, this effect is reversed if the budget refers to the High segment. In this case, an increase in the budget, y_H , of the high segment causes a decrease in the manufacturer's benefit. The reason is that customers, who due to their higher y_H can afford the fixed cost F_O of *Ownership* to a greater extent, may actually prefer to remain "loyal" to *Ownership* since it is characterized by a smaller variable cost, $c_O < p_M$. These findings stress the important role that location should play in the manufacturer's decision making.

The portion of the vehicle usage time that actual driving occurs also has a significant effect on the manufacturer's benefit. Although higher values of ω imply greater actual driving time and therefore inflict a higher total operating cost on the manufacturer (under *Membership* the manufacturer is responsible for the operating cost of the vehicle), we see that the manufacturer actually benefits more from increases in ω . The reason is that higher values of ω can strain customers' transportation budgets. In this case, customers may be more willing to choose *Membership* because they can stay within their transportation budget and either enjoy a monetary surplus or an increase in their driving time. Once more, our findings reveal the importance of location in the manufacturer's benefit. All else the same, the manufacturer should prefer to introduce *Membership* in areas where the driving patterns of the residents are characterized by larger values of ω (e.g., universities, college-towns, or areas with high-density population).

The availability of a reliable and interconnected public transportation system has been identified as one of the most important prerequisites for the success of car sharing programs (Millard-Ball et al., 2005). As a matter of fact, most car sharing schemes are located in metropolitan cities with well-developed public transportation systems (Zipcar, 2012b). In our model, the quality of the outside option is captured through the cost p_a . We have already established in Proposition 1 that increasing p_a

results in nonincreasing vehicle usage. Therefore, we expect the improvement in the manufacturer’s benefit to diminish in p_a . As p_a increases, the manufacturer will likely react by lowering p_M in an effort to encourage vehicle usage and maintain customer membership. Table 4 verifies our expectation by demonstrating the strong negative effect of p_a on the manufacturer’s benefit. A similar explanation applies to the also strong negative effect of a (probability with which customers cannot find a vehicle available in the car sharing fleet).

In our model, the parameters $h \in (0, 1)$ and c define the value, $R = hc$, that a vehicle retains after 5 years. It is clear that the residual value of the vehicle may increase either due to an increase in the percent h and/or the production cost c . If h increases, then the manufacturer can reap an additional benefit because under *Membership* she maintains the ownership of the fleet. A similar argument, however, holds true for the customers, who due to the higher residual value of the vehicles may become more inclined towards choosing *Ownership*. We find that the latter effect dominates over the former. Specifically, higher values of h hinder the manufacturer’s profit increase. Practically, this indicates that, everything else constant an auto manufacturer of lower “reputation” (regarding the vehicle quality/durability) benefits more compared to an auto manufacturer of higher “reputation” from offering *Membership*. On the other hand, if the increase in the residual value originates from an increase in the production cost, c , then this effect is reversed. An increase in the production cost will affect the pricing decisions of the manufacturer, who in order to maintain a profitable markup may have to price a customer segment out of the market. This segment may be able to become active through *Membership* causing a market expansion that clearly benefits the manufacturer. Table 4 verifies this positive effect of c .

Another important cost parameter that shapes both the manufacturer’s and customers’ decisions is the vehicle operating cost p_O (i.e., cost of gasoline). Increasing gas

prices strain customers' transportation budgets, hence making it more likely for them to choose *Membership*. However, the manufacturer's profit margin is also impinged upon since under *Membership* she is responsible for p_O . Table 4 indicates that, of these two opposing effects, the former prevails. Namely, we see that increasing prices p_O also results in a higher percent change in the manufacturer's profit. This can be clearly attributed to the customers' higher willingness to adopt *Membership* as their transportation mode. Therefore, if the auto manufacturer operates in an environment where the cost of gasoline is high, then she can significantly improve her profitability by becoming involved in the car sharing business. In this spirit, the car sharing business has the potential to be a very effective way in which auto manufacturers can hedge against or even benefit from possible federal gas tax increases. In a recent interview, General Motors CEO Dan Akerson called for a \$1 gas tax increase, claiming that both his company and the entire industry would reap significant benefits. His line of reasoning was that customers would be induced to purchase smaller and more fuel efficient cars (CNNMoney, 2011), which resonates with our explanation regarding the effect of p_O . However, offering mobility solutions in conjunction with the traditional sales channels may provide superior benefits because no changes in the product line design are required (such as design and production of new, smaller and more fuel efficient vehicles).

3.5 Discussion and Directions for Future Research

In recent years, manufacturers from various industries have started focusing on providing solutions as opposed to strictly selling their products. This trend, known as *servicization*, has also emerged in the transportation business in the form of car sharing programs. Despite the increasing popularity and remarkable growth projections of these programs, auto manufactures have been hesitant to engage in the car sharing business. In this paper we study the auto manufacturer's dilemma regarding whether

to offer car sharing in conjunction with the traditional selling of vehicles. By explicitly modeling customers' decisions regarding the choice of transportation mode and vehicle usage we are able to characterize the manufacturer's optimal strategy. The environmental implications of this strategy are also identified and compared to the claims made by car sharing providers and environmental agencies.

We find that on average the manufacturer benefits from becoming involved in car sharing. This benefit is more pronounced when customers' driving patterns are characterized by low minimum driving requirements. We are able to completely disentangle the drivers that shape the manufacturer's benefit, and we identify the pervasive character of the market expansion effect. The selling price of the vehicles changes nonmonotonically with respect to the customers' driving patterns, and it may increase or decrease compared to the selling price before the introduction of *Membership*. Consumers also benefit from the offering of *Membership* as they realize a higher surplus. The customers of the Low segment appear to benefit the most. This benefit stems from the monetary surplus that customers are able to appropriate after the introduction of *Membership*. Regarding the environmental character of the manufacturer's strategy we find that, despite the decrease in the total production volume, the total driving time increases as a result of the market expansion that the manufacturer achieves after the introduction of *Membership*. This results in the increase in the total environmental burden.

The aforementioned findings are based on a number of assumptions we made during the formulation and analysis of our model. The relaxation of some of these assumptions can further enrich our insights and offer great future research avenues. The inclusion of hybrid and electric vehicles in the car fleet can affect both the economic and environmental impacts. Although such vehicles are associated with lower operating costs and reduced emissions, they also impose a higher production cost on the manufacturer. Therefore, it is not clear whether the manufacturer would have an

incentive to include such vehicles in the car sharing fleet. We have also assumed that the manufacturer can optimally determine the selling price of the vehicles. However, it may also be true that the selling price is determined “exogenously” based on the pricing pressure from rival manufacturers. Adding the dimension of competition can provide additional interesting insights.

From a consumer modeling perspective, it has been assumed that customers are certain about their driving requirements. The introduction of uncertainty in usage can disfavor the choice of *Membership* because customers face the danger of incurring steep fees every time they exceed their reserved time.⁹ The incorporation of uncertainty could be also combined with the use of a Multinomial Logit (MNL) choice model. An MNL model can be used to capture the fact that for a variety of reasons (e.g., bounded rationality; Huang et al., 2011) consumers are known to make sub-optimal choices (i.e., choices that do not maximize their utility). Furthermore, it would be reasonable to expand the profiles of the driving patterns and assume that customers “randomize” among Profiles 1-4 with certain probabilities. Finally, the effect of customers’ environmental consciousness or other behavioral traits (i.e., endowment effect) can be assessed by assigning a wider range of values to the intrinsic preference parameters of our model.

⁹For instance, Zipcar charges \$50 per late hour while the regular hourly fee is \$7.75 (Zipcar, 2012a).

CHAPTER IV

THE IMPLICATIONS OF THE “EXPERIENCE REFERENCE EFFECT” ON THE DESIGN OF SERVICES

4.1 Introduction

Assume that you are in pursuit of legal advice and, therefore, you are seeking to hire a lawyer. During your search you become impressed by a specific law practice, which has created a very useful website on which you can find legal information and forms pertaining to your case which and also offers free consultation sessions. For that reason, you decide to conduct business with that particular law firm and allow them to handle all of your legal cases. Contemplate now the disappointment that you may experience from realizing that the law firm is not devoting as much attention to your cases as you initially expected. How does this disappointment affect your interaction with the law firm? Do you believe that you would have experienced the same level of disappointment if the firm had not invested in the website and had not offered free consultation sessions? Had this been the case, would you have decided to conduct business with the firm?

An ongoing debate among lawyers (especially new lawyers) has to do with whether offering free consultation sessions constitutes a good business practice (Rodgers, 2011). Free consultation gives the service provider the opportunity to nudge the customer towards making purchase. However, free consultation sessions are time consuming, do not necessarily result in customer commitment and are by definition free. A similar dilemma is faced by consulting firms, which may have to commit significant resources during the sales pitch period.¹ Thus, the decision of whether to

¹A relevant term used in practice is that of *consultative selling* (Hanan, 2004).

offer pre-consumption interactions with the customer is an open question for service providers.

We tackle this dilemma by adopting a process-based view of services. In particular, and as we have previously established (Chapter II), the novelty of the process-based view of services resides in the realization that in services customer “value” is not generated solely during the transaction point or the “core” offering of the service. Under this conceptualization, a service provider can decide how much effort to allocate not only at the transaction point but also before it. In order to showcase the service value and increase the likelihood of customers joining the service system, the provider may exert additional costly effort before the core of the service without obliging the customers to commit to a price. However, in this way customers may form experience expectations and anchor to an “experience reference point.” Namely, if in an effort to convince the customer to commit to the price, the provider “puts her best foot forward” before the transaction point, then the customer may form and anchor to a high reference point and expect the rest of the experiences to be as high. Therefore, any experience glitches at the core offering that fall below that reference point can cause customer *disconfirmation*, which will negatively impact the provider’s reputations or profit. In this context we formulate and characterize the optimal design in terms of effort allocation decisions of the service provider.

This essay extends the research presented in Chapter II. In Chapter II we strive to shed light on some of the decisions that a service provider (henceforth she) needs to make during the design phase of a service. However, one of the underlying assumptions in Chapter II is that the customer (henceforth he), upon entering the service system, goes through the entire service process. Namely, the customer lacks the flexibility to abandon the system (due to a sub-par service experience) and never receive the service. Such an option can have significant implications for the service provider especially if the customer has not committed irreversibly to a price before abandoning

the system.

4.2 Literature

Our positioning with respect to the service operations literature remains the same as in Chapter II. Specifically, in accordance with the papers in that stream of literature, we acknowledge the existence of variability in service systems. However, we do not make any further assumptions on the sources of the variability. Such sources may be as diverse as the stochastic service rates that result in long queues, the subjective nature of services or even the fact that customers are unable to fully articulate their preferences (Terwiesch and Loch, 2004). Carmon et al. (1995) challenge the traditional queuing analysis by focusing on the psychological implications of waiting. In their paper the service is disaggregated into two stages, the waiting time and service time segment, and it is assumed that the dissatisfaction level of the customers at each segment changes with a different rate. The focus of their paper is on how the allocation of the service to the different segments affects the customers' final dissatisfaction level in the context of *necessary services* in which customers cannot balk. The question regarding how service design decisions are affected when customers have the option to balk is left for future research.

A relatively recent stream of literature has addressed the temporal aspects of a service delivery. Drawing upon the behavioral sciences (Loewenstein et al., 1993), the studies in this stream (Chase and Dasu, 2001; Bitran et al., 2008; Dixon and Verma, 2010) investigate the effect of the sequence of service outcomes on customer experience and satisfaction. We build on this line of work by incorporating this sequence effect in the service design decisions. However, in our setting such effects are stochastic in nature. We draw on behavioral theories such as adaptive expectations and prospect theory (Kahneman and Tversky, 1979; or see Kalyanaram and Winer, 1995 for empirical evidence) to capture the customers' decision making process. Reference effects

have been studied extensively in the context of dynamic pricing strategies (Popescu and Wu, 2007; Kopalle et al., 1996). To the best of our knowledge, our work constitutes the first attempt to investigate the implications of “reference point” phenomena on the provider’s service design decisions.

Our research is closely related to that of Aflaki and Popescu (2010). They propose a behavioral dynamic model of a single firm and client relationship in which the objective of the firm is to maximize customer lifetime value (CLV). In each period, the service provider decides what service level to offer the customer. Improving service is costly, but it increases customer satisfaction and retention rate. Our work is different in that we assume static services that are not adjusted for each individual customer. In our setting, service design entails an upfront irreversible commitment (through an upfront investment) made at the blueprint level before the actual launch of the service. Thus, once the service provider decides on the optimal profile of effort (i.e., the effort she will exert at each stage of the service), this decision cannot be adjusted. Our assumption is not restrictive. Potential tactical adjustments can be captured through the stochastic nature of customer retention or abandonment. We believe that such an assumption is more realistic and easily justified in all “mass” service offerings in which the aforementioned decisions uniquely characterize the service (e.g., restaurants).

4.3 The Model

We envision the service delivery as a two-stage process, comprising a consumption stage (Stage 2; the core) and a pre-consumption stage (Stage 1). The customer’s first interaction with the service provider occurs at Stage 1 when he derives an initial experience. Based on this experience, the customer continues in Stage 2 and commits to a price (i.e., starts the consumption of the core) or abandons the service system. If the customer proceeds to Stage 2, then he derives another (core) experience. If the experience at Stage 2 is inferior to the reference point that the customer created

at Stage 1, then he realizes a discrepancy between his expectations and the actual service received. In this case, we assume that the customer will ask to be refunded by the service provider. Through the refund we capture the negative impact that customer disconfirmation may have on the provider's profit (e.g., negative word-of-mouth, customer failure to revisit the service system). In this context, the provider's problem can be characterized by equation (20).

$$\max_{e_1 \geq 0, e_2 \geq 0} \Pi = fp[e_1](1 - \delta q[e_2 - \lambda e_1]) - c_1 e_1 - c_2 e_2. \quad (20)$$

The decisions of the service provider entail the calculation of the efforts e_1 and e_2 that she exerts at the first and second stage of the service process, respectively. We assume that the price, $f > 0$, that the provider charges for the service is determined exogenously as a result of competitive pressure. In equation (20), $p[e_1] \in (0, 1)$ is the probability with which customers join the service system right after the completion of the first stage; $q[e_2 - \lambda e_1] \in (0, 1)^2$ is the probability with which customers ask for a refund if the experience at the second stage is rendered unsatisfying; $\delta \in (0, 1)$ is the fraction of the price that customers will be refunded; and c_1, c_2 represent the marginal cost of effort that the provider exerts at the first and second stage respectively. We further assume that p is increasing concave in e_1 (i.e., $\frac{\partial p}{\partial e_1} > 0$ and $\frac{\partial^2 p}{\partial^2 e_1} < 0$) and q is decreasing convex in the “effective” effort $(e_2 - \lambda e_1)$ (i.e., $\frac{\partial q}{\partial (e_2 - \lambda e_1)} < 0$ and $\frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} > 0$). The parameter $\lambda \in (0, 1)$ captures the “experience reference effect.” We assume that as the provider's effort at the second stage exceeds the effort at the first stage, the probability, $q[e_2 - \lambda e_1]$, that customers ask for a refund decreases asymptotically. Figure 23 depicts our service process.

Under the aforementioned assumptions, we proceed to the differentiation of the

²For expositional parsimony, in the rest of the analysis we omit the arguments e_1 and $e_2 - \lambda e_1$ from $p[e_1]$ and $q[e_2 - \lambda e_1]$, respectively.

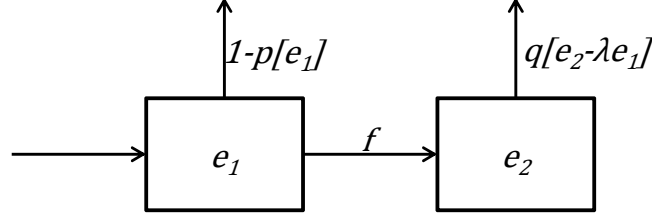


Figure 23: Service delivery process.

profit function (20).³ The signs of the first order conditions $\frac{\partial \Pi}{\partial e_1}$ and $\frac{\partial \Pi}{\partial e_2}$ are indeterminate. Therefore, the existence of an optimal profile of efforts $\mathbf{e} = \{e_1^*, e_2^*\}$ is guaranteed. The Hessian of (20) is given by $|H| = \begin{vmatrix} \frac{\partial^2 \Pi}{\partial^2 e_1} & \frac{\partial^2 \Pi}{\partial e_1 \partial e_2} \\ \frac{\partial^2 \Pi}{\partial e_2 \partial e_1} & \frac{\partial^2 \Pi}{\partial^2 e_2} \end{vmatrix}$. Since the first leading principal minor of $|H|$ is $|H_1| = \frac{\partial^2 \Pi}{\partial^2 e_1} < 0$, joint concavity of (20) is ensured if and only if the second principal minor of $|H|$ is positive. The latter is true if and only if $\delta < \hat{\delta}$. Proposition 1 summarizes our findings.

Proposition 1 *If $\delta < \hat{\delta}$, then an interior profile of efforts $\mathbf{e}^* = \{e_1^*, e_2^*\} > 0$ is guaranteed to exist. At optimality, the provider's efforts as Stage 1 and Stage 2 satisfy $\left(1 - \delta q[e_2^* - \lambda e_1^*]\right) f \frac{\partial p}{\partial e_1} \Big|_{e_1=e_1^*} = c_1 + \lambda c_2$, and $-fp\delta \frac{\partial q}{\partial(e_2 - \lambda e_1)} = c_2$.*

From the system of first order conditions, it is straightforward to show that at optimality the provider's efforts satisfy

$$\left(1 - \delta q[e_2^* - \lambda e_1^*]\right) f \frac{\partial p}{\partial e_1} \Big|_{e_1=e_1^*} = c_1 + \lambda c_2 \quad (21)$$

$$-fp\delta \frac{\partial q}{\partial(e_2 - \lambda e_1)} = c_2. \quad (22)$$

It is apparent that as δ increases the provider can satisfy i) equation (21) by either increasing e_2^* and/or decreasing e_1^* , and ii) equation (22) by either decreasing e_2^* and/or increasing e_1^* . Given that $p[e_1]$ is increasing concave in e_1 , it is more “efficient” for the provider to satisfy equations (21) and (22) by decreasing e_1^* . If δ exceeds a threshold,

³To enhance readability, we provide the technical derivations in the Appendix.

then e_1^* may obtain small values that render the business unprofitable (as $p[e_1]$ may be approaching zero), and therefore the provider may choose “extreme” solutions such as to not offer the service. This is in accordance with our intuition. Specifically, increasing values of δ imply that the amount the provider refunds the customers when they deem their experience unsatisfying also increases. If $\delta > \hat{\delta}$ exceeds a threshold $\hat{\delta}$ then the service becomes unprofitable for the provider. In the rest of the analysis we focus on the cases in which $\delta < \hat{\delta}$.

In order to further investigate the properties of e_1^* and e_2^* with respect to our problem parameters, we evoke the use of the Implicit Function Theorem. We continue our analysis by formulating the following equations,

$$G_1(e_1^*, e_2^*; f, \delta, c_1, \lambda) = \frac{\partial \Pi}{\partial e_1} \Big|_{e_1=e_1^*} = 0 \quad (23)$$

$$G_2(e_1^*, e_2^*; f, \delta, c_2, \lambda) = \frac{\partial \Pi}{\partial e_2} \Big|_{e_2=e_2^*} = 0. \quad (24)$$

Given the fact that the Jacobian determinant $|J| = \begin{vmatrix} \frac{\partial G_1}{\partial e_1^*} & \frac{\partial G_1}{\partial e_2^*} \\ \frac{\partial G_2}{\partial e_1^*} & \frac{\partial G_2}{\partial e_2^*} \end{vmatrix} = |H_2| \neq 0$, when $\delta \neq \hat{\delta}$, and that G_1 and G_2 have continuous partial derivatives with respect to all the variables and parameters, the system of equations (23)-(24) defines the implicit functions $e_1^* = g_1(f, \delta, c_1, \lambda)$ and $e_2^* = g_2(f, \delta, c_2, \lambda)$. Therefore, we can use the implicit function rule and by doing so we arrive at Propositions 2-4.

Proposition 2 *The optimal effort levels e_1^* , and e_2^* decrease in the marginal cost of efforts c_1 and c_2 .*

Proposition 2 establishes that the provider’s effort levels at Stage 1 and 2 decrease as the marginal cost of Stage 1 *and/or* Stage 2 increase. This finding reveals the dependency between the different stages in the service process. For instance, when the marginal cost of the core of the service increases, the provider will most likely decrease her effort, e_2 , at Stage 2. However, due to the possible disconfirmation,

$e_2^* - \lambda e_1^*$, that customers may be bound to experience, this decrease needs to be accompanied by a decrease in the effort level, e_1^* , at Stage 1. Similarly, if the marginal cost of effort at Stage 1 increases, then the provider reacts by decreasing the effort level e_1^* . In this case, the consequences of the experience reference effect are less pronounced; therefore, the provider has a smaller incentive to exert great effort, e_2^* , at Stage 2. Although common wisdom would dictate that the effort a service provider exerts at the core of a service should not be affected by the characteristics of other stages in the service process, we see that this is not true when the experience reference effect is present. Clearly, decisions that ignore this dependency will result in suboptimal service design.

Proposition 3 *The optimal effort levels e_1^* , and e_2^* increase in the price, f , of the service offering.*

Although, in our model the price f does not directly affect customer demand, we see that increasing prices result in increasing provider efforts at Stage 1 and 2. The reason is that increasing prices entitle customers to higher refunds. The provider mitigates this effect by increasing her effort levels at *both* stages. An increase in the effort at Stage 2 without an increase in the effort at Stage 1 would be futile, because the provider's effort, e_1^* , at Stage 1 directly affects the revenue stream through the probability $p[e_1^*]$.

Proposition 4 *The optimal effort level e_1^* , always decreases in the intensity of the experience reference effect, λ . The optimal effort level e_2^* , changes nonmonotonically with respect to the intensity of the experience effect. If $\delta < \bar{\delta}(< \hat{\delta})$, then the provider's effort at Stage 2 increases in λ . If $\delta > \bar{\delta}$, then the provider's effort at Stage 2 decreases in λ .*

In Proposition 4 we find that the optimal effort at Stage 1 decreases as the intensity of the experience reference effect, $\lambda \in (0, 1)$, increases. This is attributed to the

fact that increasing λ implies that customers are more “sensitive” to possible disconfirmation. In order to minimize the effect of disconfirmation, the provider decreases the effort she exerts at Stage 1. The change in the effort at Stage 2 is more involved. Specifically, we see that if δ is below a threshold $\bar{\delta}$, then the provider increases e_2^* with respect to λ , in an effort to decrease customer disconfirmation ($e_2^* - \lambda e_1^*$). However, this effect is reversed for higher values of $\delta (> \bar{\delta})$. As we have argued in Proposition 1, higher values of δ drive a steep decrease in e_1^* . For that reason, the provider can enjoy cost savings by decreasing e_2 without, however, causing an increase in customer disconfirmation. This nonmonotonic behavior highlights the involved character of optimal service design in the presence of the experience reference effect.

4.4 Discussion and Directions for Future Research

In this work we investigate the implications of the “experience reference effect” on the design of services. The experience reference effect describes the fact that customers may anchor to a reference point based on the experience they derive early in the service process and evaluate subsequent experiences with respect to this point. Through a stylized model, we are able to derive some fundamental service design insights whose generality is guaranteed by the lack of restrictive functional forms. Our findings capture the dependency of the stages in the services process and show that the optimal efforts decrease with respect to the marginal cost of effort and increase with respect to the price. The nonmonotonic behavior of the optimal efforts with respect to the intensity of the experience reference effect is revealed, thus indicating the involved nature of service design in the presence of experience reference effects. Additional research is required to provide a more exhaustive treatment of the subject and offer further useful managerial insights.

The inclusion of the dimension of competition can be particularly insightful. The effect of competition can be tackled from different angles. For instance, providers may

be considered to engage in price competition. In this case a price-based multinomial logit (MNL) model can be used to determine the market share of each provider (McFadden, 1973; Gaur and Park, 2007). In this context, it is not clear how the interplay between price and profile of efforts will affect the provider's design decisions in equilibrium. The competitive presence of a rival provider can also be incorporated by assuming that customers who abandon the service system of a provider at Stage 1 enter the service system of the rival provider at Stage 2. Similarly, it can also be assumed that customers who at Stage 2 deem the overall experience unsatisfying switch service providers by entering at Stage 1 of the rival provider.

Appendix A

A1. Table of Notation.

Parameters	Symbol	Definition
	n	Total number of steps that compose the customer journey.
	V_i^P	Functional benefit when the provider controls the i^{th} step.
	σ_P^2	Variance of the experience when the provider controls a step.
	$V_i^C < V_i^P$	Functional benefit when the customer performs the i^{th} step.
	$\sigma_C^2 = \delta \sigma_P^2$	Variance of the experience when the customer performs a step.
	$\delta \in (0, 1)$	Relative variability.
	$\rho \in (0, 1)$	Correlation between the realized experiences.
	$cV_i^P, c \in (0, 1)$	Cost of providing the i^{th} step.

Decision Variables	Symbol	Definition
	p	Price of service offered.
	$k \in \{0, \dots, n\}$	Number of touchpoints the provider controls.

A2. Table of Notation for the Case of Information Asymmetry.

Parameters	Symbol	Definition
	$\theta \in \{H, L\}$	The type (High/Low) of the service provider.
	$c_\theta V^P(\theta), c_\theta \in (0, 1)$	Cost for the θ -type provider to control a step.
	A^θ	The functional per-step surplus of type θ may appropriate.
	$\phi \in (0, 1)$	Customers' prior belief that the provider's type is H .
	V^E	Extra value that customers derive when they infer that $\theta = H$.
	\underline{k}_s and \bar{k}_s	The lower and upper bound that define the "mimicking" parabola. If the high-type provider chooses to control a number of touchpoints between these bounds then the low-type provider finds it profitable to mimick such action and control the same number of touchpoints.
	\underline{k}_e and \bar{k}_e	The lower and upper bound that limit the actions (i.e., number of touchpoints to control) the high-type provider finds profitable take in order to signal her type.
	\underline{k}_p and \bar{k}_p	The lower and upper bound that define the "pooling" parabola. If the high-type provider chooses to control a number of touchpoints between these bounds then the low-type provider finds it profitable to control the same number of touchpoints.

Decision Variables	Symbol	Definition
	p^θ	Price charged from the θ -type provider in equilibrium.
	$0 \leq k^\theta \leq n$	Number of touchpoints the θ -type provider controls in equilibrium.

A3. Proofs.

Lemma 1 *The overall experience a customer derives from the service offering follows the normal distribution with mean μ_V and standard deviation σ_V .*

Proof of Lemma 1. The value that a customer derives upon completion of the service process and his exit from the service system is given by equation (1). Taking the expected value of equation (1), we obtain $\mathbb{E}[\tilde{V}] = \mathbb{E}\left[\sum_{i \in \mathcal{P}_\theta} \tilde{V}_i^\theta\right] + \mathbb{E}\left[\sum_{i \in \mathcal{C} = \mathcal{J} \setminus \mathcal{P}_\theta} \tilde{V}_i^C\right] - p^\theta = \sum_{i \in \mathcal{P}_\theta} V_i^\theta + \sum_{i \in \mathcal{C} = \mathcal{J} \setminus \mathcal{P}_\theta} V_i^C - p^\theta \doteq \mu_V$. With k^θ indicating the cardinality of \mathcal{P}_θ the variance of \tilde{V} can be calculated as $Var[\tilde{V}] = Var\left[\sum_{i=1}^{k^\theta} \tilde{V}_i^\theta + \sum_{i=k^\theta+1}^n \tilde{V}_i^C - p^\theta\right] = k^\theta \sigma_P^2 + (n - k^\theta) \sigma_C^2 + 2\rho \left(\frac{k^\theta!}{2!(k^\theta-2)!} \sigma_\theta^2 + \frac{(n-k^\theta)!}{2!(n-k^\theta-2)!} \sigma_C^2 + k^\theta(n - k^\theta) \sigma_\theta \sigma_C\right)$ which simplifies to:

$$Var[\tilde{V}] = (n - k^\theta)(1 + (n - k^\theta - 1)\rho) \sigma_C^2 + k^\theta(1 + (k^\theta - 1)\rho) \sigma_\theta^2 + 2k^\theta(n - k^\theta) \rho \sigma_C \sigma_\theta \doteq \sigma_V^2. \square$$

Lemma 2 *The risk averse customer obtains the following expected utility upon receiving service from the provider: $\mathbb{E}[U(\tilde{V})] = -e^{-r(\mu_V - \frac{r}{2}\sigma_V^2)}$.*

Proof of Lemma 2. We assume that customers are risk averse with the von-Neumann Morgenstern utility function $U(\tilde{V}) = -e^{-r\tilde{V}}$. It is easy to show that $\mathbb{E}[U(\tilde{V})] = -e^{-r(\mu_V - \frac{r}{2}\sigma_V^2)}$ (Sargent, 1987, pg.154-155). \square

Lemma 3 *There exists a price $\bar{p}(k) \in \mathbb{R}_+^*$ such that the total market share for the provider is 1 if and only if $p \leq \bar{p}(k)$. Otherwise, no customers deem the service beneficial and the resulting market share is 0.*

Proof of Lemma 3. The customer's expected utility $\mathbb{E}[U(\tilde{V})]$ is monotonic increasing in $\mu_V - \frac{r}{2}\sigma_V^2$. Thus, $\mathbb{E}[U(\tilde{V}_1)] \geq \mathbb{E}[U(\tilde{V}_2)]$ implies $\mu_{V_1} - \frac{r}{2}\sigma_{V_1}^2 \geq \mu_{V_2} - \frac{r}{2}\sigma_{V_2}^2$. A customer deems the service beneficial if and only if $\mathbb{E}[U(\tilde{V}(p, \mathcal{P}))] \geq \mathbb{E}[U(\tilde{V}(p = 0, \mathcal{P} = \emptyset))]$. Using k to indicate the cardinality of \mathcal{P} , we expand the inequality as follows:

$$\begin{aligned} & -p + \sum_{i \in \mathcal{C}} V_i^C + \sum_{i \in \mathcal{P}} V_i^P + V^E \\ & -\frac{1}{2}r\left(k + (k-1)kp + 2k(n-k)\delta\rho + (n-k)\delta^2(1 + (n-k-1)\rho)\right)\sigma_P^2 \geq \frac{nr\delta^2(-1 + (1-n)\rho)\sigma_P^2}{2} + \sum_{i \in \mathcal{J}} V_i^C \Leftrightarrow \\ & p \leq \frac{1}{2}kr(1-\delta)\left(-1 + (1-k)\rho + \delta(-1 + (1+k-2n)\rho)\right)\sigma_P^2 + V^E + \sum_{i \in \mathcal{P}} [V_i^P - V_i^C] \doteq \bar{p}(k). \square \end{aligned}$$

Proof of Propositions 1&2. We first use an exchange argument to show that the touchpoints should be assigned in decreasing order of A_i for $i \in \{1, \dots, n\}$. Let $A_{[j]}$ indicate the j^{th} element of the ordering. Assume that the service provider decides to control k steps. Additionally assume that the provider can use two different configurations (out of the $\frac{n!}{(n-k)!}$ possible configurations) for the choice of the touchpoints. In the first configuration the touchpoints are chosen such that $A_{[j-1]} \geq A_{[j]}$, i.e., $\mathcal{P}_1 = \{A_{[1]}, A_{[2]}, \dots, A_{[k-1]}, A_{[k]}\}$. In the second configuration the touchpoints are chosen such that $A_{[j-1]} \geq A_{[j]} \geq A_{[j+w]}$, $\forall w \in \{1, \dots, n-k-1\}$, i.e., $\mathcal{P}_2 = \{A_{[1]}, A_{[2]}, \dots, A_{[k-1]}, A_{[k+w]}\}$. It is evident from (4) that $\Pi(\mathcal{P}_2) - \Pi(\mathcal{P}_1) = A_{[k+w]} - A_{[k]} \leq 0$. Repeating this for any w and additional steps before k , proves the claim that the provider's optimal decision is to choose to control the touchpoints of the first configuration.

We now intend to establish the concavity of the provider's profit function (4). For that reason we calculate the second order backward difference $(\Pi(p = \bar{p}(k^* + 1), k^* + 1) - \Pi(p = \bar{p}(k^*), k^*)) - (\Pi(p = \bar{p}(k^*), k^*) - \Pi(p = \bar{p}(k^* - 1), k^* - 1))$, which results in $-r(1 - \delta)^2 \rho \sigma_P^2 - (A_{[k^*]} - A_{[k^*+1]}) \leq 0$. Therefore, our profit function is always concave in k . In order now to identify the optimal integer k^* , we proceed to the calculation of the first order forward and backward differences. Namely, $\Pi(p = \bar{p}(k^* + 1), k^* + 1) - \Pi(p = \bar{p}(k^*), k^*)$ is negative if and only if $\frac{r(1-\delta)(-1-2k^*\rho+\delta(-1+2(1+k^*-n)\rho))\sigma_P^2}{2} + A_{[k^*+1]} \leq 0$ which is equivalent to $k^* \geq \frac{2A_{[k^*+1]} - r(1-\delta)(1+\delta+2(n-1)\delta\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2} \doteq \underline{k}$. Similarly, $\Pi(p = \bar{p}(k^*), k^*) - \Pi(p = \bar{p}(k^* - 1), k^* - 1)$ is positive if and only if $\frac{r(1-\delta)(-1-\delta+2(1+k^*(-1+\delta)-n\delta)\rho)\sigma_P^2}{2} + A_{[k^*]} \geq 0$ which is equivalent to $k^* \leq \frac{2A_{[k^*]} - r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2} \doteq \bar{k}$. It is also straightforward to show that $\bar{k} - \underline{k} = 1$. Since the concavity of (4) has already been established, the optimal integer number of steps is given by $k^* = \lfloor \bar{k} \rfloor = \left\lfloor \frac{2A_{[k^*]} - r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2} \right\rfloor$. The optimal number of steps k^* will be an interior solution if and only if $\lfloor \bar{k} \rfloor \in \{1, \dots, n-1\}$. Specifically, $\bar{k} < n$ if and only if $\frac{2A_{[k^*]} - r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2} - n < 0$. The latter inequality is decreasing in σ_P^2 , therefore it is true only when $\sigma_P^2 > \frac{2A_{[k^*]}}{r(1-\delta)(1+\delta+2(n-1)\rho)} \doteq \underline{\sigma}_P^2$. Similarly, $\bar{k} \geq 1$ if and only if $\frac{2A_{[k^*]} + r(-1+\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2} - 1 \geq 0$ which is decreasing in σ_P^2 . As such, it holds only when $\sigma_P^2 \leq \frac{2A_{[k^*]}}{r(1-\delta)(1+\delta+2(n-1)\delta\rho)} \doteq \bar{\sigma}_P^2$. It is easy to establish that $\bar{\sigma}_P^2 - \underline{\sigma}_P^2 = \frac{4(n-1)\rho A_{[k^*]}}{r(1+\delta+2(n-1)\rho)(1+\delta+2(n-1)\delta\rho)} \geq 0$. In the special case where

$A_i = A \forall i \in \{1, 2, \dots, n\}$, the provider's optimal profit is $\Pi^* = \Pi(\lfloor \bar{k} \rfloor) \geq \Pi(\bar{k}) = \frac{(-2A+r(1-\delta)(1+\delta+2(n-1)\delta\rho)\sigma_P^2)(-2A+r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2)}{8r(1-\delta)^2\rho\sigma_P^2} \geq 0 \forall \sigma_P^2 \in (\underline{\sigma}_P^2, \bar{\sigma}_P^2)$.

Proof of Proposition 3. For a given k we have $\frac{\partial \bar{k}(\delta)}{\partial \delta} = \frac{-2A_{[k]}+r(1-\delta)(1+(n-1)\rho)\sigma_P^2}{r(-1+\delta)^3\rho\sigma_P^2}$. It can be established that $\frac{\partial \bar{k}(\delta)}{\partial \delta} \leq 0$ if and only if $\delta \in \left(0, \frac{n-1}{2n-1}\right)$, $\rho \in \left(\frac{\delta}{(n-1)(1-2\delta)}, 1\right)$ and $\sigma_P^2 \in \left(\frac{2A_{[k]}}{r(1-\delta)(1+(n-1)\rho)}, \bar{\sigma}_P^2\right)$. In this case, for small changes of $\epsilon > 0$ magnitude and $\forall k \in \{1, \dots, n\}$ we have $\bar{k}(\delta = \delta + \epsilon) \leq \bar{k}(\delta)$ which implies $\lfloor \bar{k}(\delta = \delta + \epsilon) \rfloor \leq \lfloor \bar{k}(\delta) \rfloor$. Therefore, $k^*(\delta = \delta + \epsilon) \leq k^*(\delta)$. In similar fashion, we obtain: i) $\frac{\partial \bar{k}(r)}{\partial r} = \frac{-A_{[k]}}{r^2(1-\delta)^2\rho\sigma_P^2} \leq 0 \forall \sigma_P^2$, which implies $k^*(r = r + \epsilon) \leq k^*(r)$, ii) $\frac{\partial \bar{k}(n)}{\partial n} = -\frac{\delta}{1-\delta} \leq 0 \forall \sigma_P^2$, which implies $k^*(n = n + \epsilon) \leq k^*(n)$, iii) $\frac{\partial \bar{k}(\rho)}{\partial \rho} = \frac{-2A_{[k]}+r(1-\delta^2)\sigma_P^2}{2r(1-\delta)^2\rho^2\sigma_P^2} \leq 0 \forall \sigma_P^2 \in (\underline{\sigma}_P^2, \bar{\sigma}_P^2)$, which implies $k^*(\rho = \rho + \epsilon) \leq k^*(\rho)$, and iv) $\frac{\partial \bar{k}(\sigma_P^2)}{\partial \sigma_P^2} = \frac{-A_{[k]}}{r(1-\delta)^2\sigma_P^4\rho} \leq 0$, which implies $k^*(\sigma_P^2 = \sigma_P^2 + \epsilon) \leq k^*(\sigma_P^2)$. \square

Proof of Proposition 4. In the rest of the analysis we use the real solution $k^* = \bar{k}$ as opposed to the integer rounding $k^* = \lfloor \bar{k} \rfloor$ which may result in slight abuse of notation (slightly weaker or stronger inequalities).⁴ In what follows we use the notation $\Pi(\theta, \phi', p, k)$ to indicate the profit of the θ -type provider when in equilibrium she charges a price p , controls k steps and the customers assign a *posterior* probability ϕ' to her being of high type. For example, $\Pi(H, 0, p, k)$ indicates the profit that the high-type provider derives when she charges p , chooses to control k steps and the customers believe that she is a low-type provider. Under the assumptions stated in §2.4.2, the values of μ_V and σ_V^2 calculated in Lemma 1 are now given by $\mu'_V = \mu_V + \phi'V^E$ and $\sigma'^2_V = \sigma_V^2$. In order for the price to signal type, the necessary and sufficient conditions for the same number of steps k are: i) $\Pi(L, 0, \bar{p}(k), k) \geq \Pi(L, 1, p^H(k), k)$ or equivalently $\bar{p}(k) - kc_LV^P \geq p^H(k) - kc_LV^P + V^E$ which is true when $p^H(k) \leq \bar{p}(k) - V^E$ and ii) $\Pi(H, 1, p^H(k), k) \geq \Pi(H, 0, \bar{p}(k), k)$ or equivalently $p^H(k) - kc_HV^P + V^E \geq \bar{p}(k) - kc_HV^P$ which holds when $p^H(k) \geq \bar{p}(k) - V^E$. Therefore, we conclude that in equilibrium the price $p^H(k) = \bar{p}(k) - V^E$ can indeed signal

⁴Games where the players' sets of actions are integer points belong to relatively new class of strategic games called integer programming games. Such games have recently attracted growing interest from researchers (Köppe et al., 2008); however, such an analysis lies beyond the scope of our paper. Instead, we use the real proxy to focus on the managerial implications. As already shown in the proof of Propositions 1&2, it is fair to assume that moderate levels of r and σ_P^2 result in a concave profit function. Hence, a concave profit function, along with the fact that $k^* \in (\underline{k}, \bar{k})$ and $\bar{k} - \underline{k} = 1$, assures us that the use of \bar{k} instead of $\lfloor \bar{k} \rfloor$ does not practically change the nature of our results.

type. However, this is less efficient than using $k = k^H$ as a signal, since $\Pi(\bar{p}(k^H), k^H) - \Pi(p^H(k^H), k^H) = \bar{p}(k^H) - c_H k^H V^P + V^E - (p^H(k^H) - c_H k^H V^P + V^E) = V^E > 0. \square$

Lemma 4 *In any separating equilibrium the design choice of the high-type provider k^H is such that: (i) $k^H \geq \bar{k}_s(V^E)$ or $k^H \leq \underline{k}_s(V^E)$; the bounds $\bar{k}_s(V^E)$ and $\underline{k}_s(V^E)$ define a “mimicking parabola” inside of which the low-type provider always mimicks the high-type provider. (ii) $k^H \in [\max\{0, \underline{k}_e(V^E)\}, \min\{\bar{k}_e(V^E), n\}]$; the bounds $\bar{k}_e(V^E)$ and $\underline{k}_e(V^E)$ define a “participation” region where the high-type provider can profitably seek a separation equilibrium.*

Proof of Lemma 4. A necessary condition for a separating equilibrium to exist is that the low-type provider should prefer to reveal her type over mimicking the high-type provider. This requirement is mathematically translated as $\Pi(L, 0, \bar{p}(\bar{k}(L)), \bar{k}(L)) \geq \Pi(L, 1, \bar{p}(k^H), k^H)$ which holds if and only if $\bar{p}(\bar{k}(L)) - \bar{k}(L)c_L V^P \geq \bar{p}(k^H) - k^H c_L V^P + V^E$ or equivalently $k^H \notin (\underline{k}_s(V^E), \bar{k}_s(V^E))$. We assume that if customers infer that the provider is of low type then $V^E = 0$. By solving $\Pi(L, 0, \bar{p}(\bar{k}(L)), \bar{k}(L)) = \Pi(L, 1, \bar{p}(k^H), k^H)$, we obtain the bounds $\underline{k}_s(V^E)$ and $\bar{k}_s(V^E)$ respectively as $\frac{2\bar{k}(L)-1}{2} \mp \frac{1}{2} \sqrt{\frac{8V^E + r\rho(1-\delta)^2\sigma_P^2}{r\rho(1-\delta)^2\sigma_P^2}}$ with $\bar{k}(L) = \frac{2A^L - r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2}$. Also by equating $\underline{k}_s(V^E)$ with $k_s(V^E)$ we obtain $\bar{V}^E = -\frac{r(1-\delta)^2\rho\sigma_P^2}{8} < 0$, which indicates the minimum V^E at which the high-type provider can be mimicked by the low-type provider. The fact that \bar{V}^E is negative means that mimicking is always possible. For the separating equilibrium to exist it suffices that the high-type provider never finds it profitable to deviate from it. If the customer observes such a deviation he infers that the provider is a low-type one. Thus, the best alternative for a deviating high-type provider is to control $\bar{k}(L)$ number of steps. Such deviation is not profitable when $\Pi(H, 1, \bar{p}(k^H), k^H) \geq \Pi(H, 0, \bar{p}(\bar{k}(L)), \bar{k}(L))$ or equivalently $\bar{p}(k^H) - k^H c_H V^P + V^E \geq \bar{p}(\bar{k}(L)) - \bar{k}(L)c_H V^P$. The latter holds for $k^H \in [\underline{k}_e(V^E), \bar{k}_e(V^E)]$, where $\underline{k}_e(V^E)$ and $\bar{k}_e(V^E)$ are the solutions $\frac{2\bar{k}(H)-1}{2} \mp \frac{1}{2} \sqrt{1 + \frac{4(A^H - A^L)^2 - 4r(A^H - A^L - 2V^E)(1-\delta)^2\rho\sigma_P^2}{r^2\rho^2(1-\delta)^4\sigma_P^4}}$, with $\bar{k}(H) = \frac{2A^H - r(1-\delta)(1+\delta+2(n\delta-1)\rho)\sigma_P^2}{2r(1-\delta)^2\rho\sigma_P^2}$ and $A^H - A^L = (c_L - c_H) V^P. \square$

Proof of Proposition 5. In order to calculate the maximum V^E at which the high-type provider can employ the full information design strategy, we identify the following two cases:

I. When $c_H < c_L$, then $\bar{k}(H) = \bar{k}_s(V^E)$ implies $\frac{1}{2} \left(-1 + \frac{2(A^L - A^H)}{r(1-\delta)^2 \rho \sigma_P^2} + \sqrt{\frac{8V^E + r(1-\delta)^2 \rho \sigma_P^2}{r \rho (1-\delta)^2 \sigma_P^2}} \right) = 0$ which holds at $V^E = \frac{(A^L - A^H)(A^L - A^H - r(1-\delta)^2 \rho \sigma_P^2)}{2r \rho (1-\delta)^2 \sigma_P^2} \doteq \hat{V}^E \geq 0$.

II. When $c_H > c_L$, then $\bar{k}(H) = \bar{k}_s(V^E)$

a. at $\hat{V}^E \leq 0$ if $c_H - c_L < \frac{r(1-\delta)^2 \rho \sigma_P^2}{2V^P}$. Thus, it is never profitable for the provider to employ the full information strategy.

b. at \hat{V}^E if $c_H - c_L > \frac{r(1-\delta)^2 \rho \sigma_P^2}{2V^P}$. The provider is able to employ the full information strategy $\forall V^E \in [0, \hat{V}^E]$ only when $c_H - c_L > \frac{r(1-\delta)^2 \rho \sigma_P^2}{V^P} > \frac{r(1-\delta)^2 \rho \sigma_P^2}{2V^P}$. \square

Proof of Proposition 6. According to Lemma (4), if a separating equilibrium k^H exists then $k^H \in [\bar{k}_s(V^E), \bar{k}_e(V^E)]$ when $\bar{k}_s(V^E) \geq \underline{k}_e(V^E)$ or $k^H \in [\underline{k}_e(V^E), \underline{k}_s(V^E)]$ when $\underline{k}_e(V^E) \leq \bar{k}_s(V^E)$. With some simple but rather tedious algebraic calculations, we can show when these requirements are satisfied. Specifically, by utilizing equations (25)-(28)

$$\begin{aligned} \bar{k}_e(V^E) - \bar{k}_s(V^E) &= \frac{1}{2} \sqrt{1 + \frac{4(A^H - A^L)^2 - 4r(A^H - A^L - 2V^E)(1-\delta)^2 \rho \sigma_P^2}{r^2 \rho^2 (1-\delta)^4 \sigma_P^4}} \\ &\quad + \frac{A^H - A^L}{r(1-\delta)^2 \rho \sigma_P^2} - \frac{1}{2} \sqrt{\frac{8V^E + r \rho (1-\delta)^2 \sigma_P^2}{r \rho (1-\delta)^2 \sigma_P^2}} \end{aligned} \quad (25)$$

$$\begin{aligned} \bar{k}_e(V^E) - \underline{k}_s(V^E) &= \frac{1}{2} \sqrt{1 + \frac{4(A^H - A^L)^2 - 4r(A^H - A^L - 2V^E)(1-\delta)^2 \rho \sigma_P^2}{r^2 \rho^2 (1-\delta)^4 \sigma_P^4}} \\ &\quad + \frac{A^H - A^L}{r(1-\delta)^2 \rho \sigma_P^2} + \frac{1}{2} \sqrt{\frac{8V^E + r \rho (1-\delta)^2 \sigma_P^2}{r \rho (1-\delta)^2 \sigma_P^2}} \end{aligned} \quad (26)$$

$$\begin{aligned} \bar{k}_s(V^E) - \underline{k}_e(V^E) &= \frac{1}{2} \sqrt{1 + \frac{4(A^H - A^L)^2 - 4r(A^H - A^L - 2V^E)(1-\delta)^2 \rho \sigma_P^2}{r^2 \rho^2 (1-\delta)^4 \sigma_P^4}} \\ &\quad + \frac{A^L - A^H}{r(1-\delta)^2 \rho \sigma_P^2} + \frac{1}{2} \sqrt{\frac{8V^E + r \rho (1-\delta)^2 \sigma_P^2}{r \rho (1-\delta)^2 \sigma_P^2}} \end{aligned} \quad (27)$$

$$\begin{aligned} \underline{k}_s(V^E) - \underline{k}_e(V^E) &= \frac{1}{2} \sqrt{1 + \frac{4(A^H - A^L)^2 - 4r(A^H - A^L - 2V^E)(1-\delta)^2 \rho \sigma_P^2}{r^2 \rho^2 (1-\delta)^4 \sigma_P^4}} \\ &\quad + \frac{A^L - A^H}{r(1-\delta)^2 \rho \sigma_P^2} - \frac{1}{2} \sqrt{\frac{8V^E + r \rho (1-\delta)^2 \sigma_P^2}{r \rho (1-\delta)^2 \sigma_P^2}} \end{aligned} \quad (28)$$

we show that

I. If $c_H < c_L$ then $\bar{k}_e(V^E) - \bar{k}_s(V^E) \geq 0$ and $\bar{k}_s(V^E) - \underline{k}_e(V^E) \geq 0$, which together imply that $\bar{k}_s(V^E) \in [\underline{k}_e(V^E), \bar{k}_e(V^E)]$. Therefore, a plethora of separating equilibria

$k^H \in [\bar{k}_s(V^E), \bar{k}_e(V^E)]$ exists. However, all $k^H \in (\bar{k}_s(V^E), \bar{k}_e(V^E)]$ fail the intuitive criterion. Specifically, consider the equilibrium according to which $k^L = \bar{k}(L)$ and $k^H = k \in (\bar{k}_s(V^E), \bar{k}_e(V^E)]$. The customer knows that the low-type provider has no incentive to deviate from her equilibrium. For that reason, if the customer observes a deviation from k to $k' < k$, he infers that the high-type provider was responsible for it. Given the provider's concave profit function and the fact that separation is costly, the high-type provider indeed has an incentive to deviate from k to k' , violating in this way the intuitive criterion. The only k that the provider has no incentive to deviate from is $\bar{k}_s(V^E)$ since for any $\epsilon > 0$, the number $\bar{k}_s(V^E) - \epsilon$ falls inside the mimicking parabola.

- II. If $c_H > c_L$, then $\bar{k}_e(V^E) - \underline{k}_s(V^E) \geq 0$ and $\underline{k}_s(V^E) - \underline{k}_e(V^E) \geq 0$, which imply that $\underline{k}_s(V^E) \in [\underline{k}_e(V^E), \bar{k}_e(V^E)]$. A multitude of equilibria $k^H \in [\underline{k}_s(V^E), \underline{k}_e(V^E)]$ exists in this case too. Using exactly the same reasoning, we conclude that all the equilibria $k^H \in (\underline{k}_s(V^E), \underline{k}_e(V^E))$ fail the intuitive criterion. The resulting separating equilibrium is $\underline{k}_s(V^E)$.

The difference $\bar{k}(H) - \bar{k}_s(V^E) = \frac{1}{2} \left(-1 + \frac{2(A^L - A^H)}{r(1-\delta)^2 \rho \sigma_P^2} + \sqrt{\frac{8V^E + r(1-\delta)^2 \rho \sigma_P^2}{r\rho(1-\delta)^2 \sigma_P^2}} \right)$ is increasing in V^E , therefore $\bar{k}_s(V^E) \geq k^*(H) \forall V^E \geq \hat{V}^E$. Using the same rationale, it is also straightforward to establish that $\underline{k}_s(V^E) \leq k^*(H) \forall V^E \geq \hat{V}^E$. Additionally, by solving $\bar{k}_s(V^E) - n = 0$ and $\underline{k}_s(V^E) = 0$ we respectively obtain:

$$\hat{V}_n^E = \frac{(-2A^L + r(1-\delta)(1+\delta+2(n-1)\rho)\sigma_P^2)(-2A^L + r(1-\delta)(1+\delta+2(n-\delta)\rho)\sigma_P^2)}{8r(1-\delta)^2 \rho \sigma_P^2},$$
and $\hat{V}_0^E = \hat{V}_n^E + \frac{(2A^L - r(1-\delta^2)(1+(n-1)\rho)\sigma_P^2)n}{2}$. It is easy to see that $\underline{k}_s(V^E = 0) = \underline{k}(L) > 0$ and $\bar{k}_s(V^E = 0) = \underline{k}(L) + 1 = \bar{k}(L) < n$. Since $\underline{k}_s(V)$ and $\bar{k}_s(V^E)$ are monotonic decreasing and increasing respectively in V^E , then both \hat{V}_n^E and \hat{V}_0^E are positive. \square

Proof of Proposition 7. The low-type provider does not find it profitable to mimic the actions of the high-type provider when $\Pi(L, 0, \bar{p}(\bar{k}(L)), \bar{k}(L)) \geq \Pi(L, 1, p^H, k^H)$. This can be expressed as $\bar{p}(\bar{k}(L)) - \bar{k}(L)c_L V^P \geq p^H - k^H c_L V^P + V^E$ which holds for $p^H \leq \bar{p}(\bar{k}(L)) + (k^H - \bar{k}(L))c_L V^P - V^E < \bar{p}(k^H) \forall V^E > \hat{V}_n^E$. Profit is increasing in p^H , therefore the service provider faces the maximization problem, $\max_{k^H, p^H} p^H - k^H c_H V^P + V^E$

subject to $p^H = \bar{p}(\bar{k}(L)) + (k^H - \bar{k}(L))c_L V^P - V^E$. After substituting the constraint into the maximization problem we obtain $\max_{k^H} \bar{p}(\bar{k}(L)) - \bar{k}(L)c_L V^P + k^H(c_L - c_H)V^P$ which is linear in k^H and results in the two cases according to which: i) if $c_L < c_H$ then $k^H = 0$ and $p^H = 0$ and ii) if $c_L > c_H$ then $k^H = n$ and $p^H = \bar{p}(\bar{k}(L)) + (n - \bar{k}(L))c_L V^P - V^E < \bar{p}(n) \forall V^E > \hat{V}_n^E$. For the latter case, in order to verify that the high-type provider finds it profitable to employ the strategy (k^H, p^H) as opposed to employing $(\bar{k}(L), \bar{p}(k(L)))$, we compare $\Pi(H, 1, p^H, k^H) = \bar{p}(\bar{k}(L)) + (k^H - \bar{k}(L))c_L V^P - k^H c_H V^P$ with $\Pi(H, 0, \bar{p}(k(L), \bar{k}(L))) = \bar{p}(k(L)) - \bar{k}(L)c_H V^P$. Given $c_L > c_H$ and $k^H = n > \bar{k}(L)$ it is easy to show that $\Pi(H, 1, p^H, k^H) \geq \Pi(H, 0, \bar{p}(k(L), \bar{k}(L)))$. \square

Lemma 5 *In any pooling equilibrium, the service design shall be such that $k^P \in (\max\{0, \underline{k}_p(V^E)\}, \min\{\bar{k}_p(V^E), n\}) \forall V^E \geq 0$. The values $\underline{k}_p(V^E)$ and $\bar{k}_p(V^E)$ are such that $(\underline{k}_p(V^E), \bar{k}_p(V^E)) \subset (\underline{k}_s(V^E), \bar{k}_s(V^E))$, where $\underline{k}_s(V^E)$ and $\bar{k}_s(V^E)$ are defined in Lemma 4. The two sets are equal when the customers' prior belief ϕ that the provider is of high type converges to certainty $\phi \rightarrow 1$.*

Lemma 5, similar to Lemma 4, defines the “pooling parabola” inside of which a high-type service provider may be inclined to follow a pooling strategy, that is, define an uninformative service design. For this to happen, a low-type provider should not find it profitable to deviate to her full information optimal number of touchpoints. Any number of touchpoints k^P such that $k^P \in (\max\{0, \underline{k}_p(V^E)\}, \min\{\bar{k}_p(V^E), n\})$ satisfies this prerequisite. The “pooling” parabola is such that it is always inside the “mimicking” parabola.

Proof of Lemma 5. A pooling equilibrium may exist only when the provider that bears the highest marginal cost does not find it profitable to deviate to her full information optimal number of steps. When $c_L > c_H$, such requirement can be expressed as $\Pi(L, \phi, \bar{p}(k^P), k^P) \geq \Pi(L, 0, \bar{p}(\bar{k}(L)), \bar{k}(L))$ or equivalently $\bar{p}(k^P) + \phi V^E - k^P c_L V^P \geq \bar{p}(\bar{k}(L)) - \bar{k}(L)c_L V^P$ which holds for all $k^P \in (\underline{k}_p(V^E), \bar{k}_p(V^E))$. The bounds $\underline{k}_p(V^E)$ and $\bar{k}_p(V^E)$ are given by $\frac{2\bar{k}(L)-1}{2} \mp \frac{1}{2} \sqrt{\frac{8\phi V^E + r\rho(1-\delta)^2 \sigma_P^2}{r\rho(1-\delta)^2 \sigma_P^2}}$. Since $\phi \in (0, 1)$, by comparing $\underline{k}_p(V^E)$ and $\bar{k}_p(V^E)$ with $\underline{k}_s(V^E)$ and $\bar{k}_s(V^E)$ it becomes easy to see that $(\underline{k}_p(V^E), \bar{k}_p(V^E)) \subset (\underline{k}_s(V^E), \bar{k}_s(V^E))$. Additionally, by equating $\underline{k}_p(V^E)$ with $\bar{k}_p(V^E)$ we obtain $\underline{V}^E = -\frac{r(1-\delta)^2 \rho \sigma_P^2}{8\phi} <$

0, which indicates the minimum V^E at which pooling can occur. As expected, \underline{V}^E is negative which implies that pooling is possible $\forall V^E$. \square

Proof of Proposition 8. Applying the same steps as in the proof of Proposition 5 we calculate $\hat{V}^E(\phi) = \frac{(A^L - A^H)(A^L - A^H - r(1-\delta)^2 \rho \sigma_P^2)}{2\phi r \rho (1-\delta)^2 \sigma_P^2}$. If $V^E \geq \hat{V}^E(\phi)$ then $\bar{k}(H) < \bar{k}_p(V^E)$ when $c_H - c_L < \frac{r(1-\delta)^2 \rho \sigma_P^2}{2V^P}$ and $\bar{k}(H) > \bar{k}_p(V^E)$ when $c_H - c_L > \frac{r(1-\delta)^2 \rho \sigma_P^2}{2V^P}$. In both of these cases the high-type provider would want to control $\bar{k}(H)$ steps. Since $\bar{k}(H) \in (\underline{k}_p(V^E), \bar{k}_p(V^E))$, the low-type provider is also willing to “pool” at $\bar{k}(H)$. If $V^E \leq \hat{V}^E(\phi)$, then $\bar{k}(H) \notin (\underline{k}_p(V^E), \bar{k}_p(V^E))$ and the low-type provider is not willing to pool. While for any $k^P \in (\underline{k}_p(V^E), \bar{k}_p(V^E))$ the low-type provider is always better off by pooling as opposed to revealing her true type, the high-type provider would always choose the same $\bar{k}(H)$ number of steps. For any $k^P \neq \bar{k}(H)$ the high-type provider would have an incentive to deviate to $\bar{k}(H)$ and thus break the equilibrium. \square

Proof of Corollary 1. To prove Corollary 1 we need to compare for each case the profit a high-type provider makes in a separating equilibrium (if attainable) with the profit she makes in pooling equilibrium. We proceed case by case as follows.

- I. In Proposition 7 we identify the actions a high-type provider must take in order to signal her type. We compare now the profit resulting from the proposed actions with the profit resulting from a pooling equilibrium. We find that if the customers’ prior belief exceeds $\tilde{\phi}$, then the high-type provider prefers the pooling equilibrium. Specifically, $\Pi(H, \phi, \bar{p}(k^P) + \phi V^E, k^P) - \Pi(H, 1, p^H, k^H) \geq 0$ if and only if

$$\begin{aligned} & \frac{(c_H - c_L) V^P (2V^C + (-2 + c_H + c_L) V^P)}{2r(1-\delta)^2 \rho \sigma_P^2} \\ & - \frac{r(1-\delta)(2\phi V^E(-1+\delta)\rho - c_H V^P(1+\delta(1-\rho) - \rho + 2n\rho) + c_L V^P(1+\delta - (1-2n+\delta)\rho)) \sigma_P^2}{2r(1-\delta)^2 \rho \sigma_P^2} \geq 0 \Leftrightarrow \\ & \phi \geq - \frac{(c_H - c_L) V^P (2V^C + (-2 + c_H + c_L) V^P - r(1-\delta)(-1+\delta(-1+\rho) + \rho - 2n\rho) \sigma_P^2)}{2rV^E(1-\delta)^2 \rho \sigma_P^2} \doteq \tilde{\phi} \end{aligned}$$

- II. Using the same rationale as in Case I we make the following comparison:

$$\begin{aligned} & \Pi(H, \phi, \bar{p}(k^P) + \phi V^E, k^P) - \Pi(H, 1, \bar{p}(k^H), \bar{k}^H) \geq 0 \Leftrightarrow \\ & \frac{(c_H - c_L)^2 r V^P (1-\delta)^2 \rho \sigma_P^2 + 2\phi r^2 V^E (-1+\delta)^4 \rho^2 \sigma_P^4 + (c_H - c_L) V^P \sqrt{r^3 (-1+\delta)^6 \rho^3 \sigma_P^6 (8V^E + r(-1+\delta)^2 \rho \sigma_P^2)}}{2r^2 (-1+\delta)^4 \rho^2 \sigma_P^4} \geq 0 \Leftrightarrow \\ & \phi \geq - \frac{(c_H - c_L) V^P ((c_H - c_L) r V^P (1-\delta)^2 \rho \sigma_P^2 + \sqrt{r^3 (1-\delta)^6 \rho^3 \sigma_P^6 (8V^E + r(1-\delta)^2 \rho \sigma_P^2)})}{2r^2 V^E (1-\delta)^4 \rho^2 \sigma_P^4} \doteq \tilde{\phi} \end{aligned}$$

- III. This case is trivially true since we have already established that a separating equilibrium is not attainable.

IV. The proof is the same as in Case II, where after replacing \bar{k}^H with \underline{k}^H we obtain

$$\phi \geq \bar{\phi} + \frac{(c_H - c_L) V^P \sqrt{r^3(1-\delta)^6 \rho^3 \sigma_P^6 (8V^E + r(1-\delta)^2 \rho \sigma_P^2)}}{2r^2 V^E (1-\delta)^4 \rho^2 \sigma_P^4} \doteq \check{\phi}. \square$$

A4. Additional Figures.

In this setting, once customers infer that $\theta = H$, then they derive an extra value kV^E , with $k \in (0, n)$. The values of μ_V and σ_V^2 are now given by $\mu'_V = \mu_V + \phi' k V^E$ and $\sigma_V'^2 = \sigma_V^2$. Figures 24-27 depict the signaling strategies of the high-type provider. The expressions for the new bounds are shown below.

$$\begin{aligned} \underline{k}_s \text{ and } \bar{k}_s &= \frac{2\bar{k}(L) - 1}{2} + \frac{V^E}{r(1-\delta)^2 \rho \sigma_P^2} \\ &\quad \mp \sqrt{\frac{4V^E(V^E + 2A^L) + 4rV^E(-1+\delta)(1+\delta-\rho + (-1+2n)\delta\rho)\sigma_P^2 + r^2(-1+\delta)^4 \rho^2 \sigma_P^4}{4r^2(-1+\delta)^4 \rho^2 \sigma_P^4}} \\ \underline{k}_e \text{ and } \bar{k}_e &= \frac{2\bar{k}(H) - 1}{2} + \frac{V^E}{r(1-\delta)^2 \rho \sigma_P^2} \\ &\quad \mp \sqrt{\frac{4V^E(V^E + 2A^H) + 4rV^E(-1+\delta)(1+\delta + (-1-\delta+2n)\delta\rho)\sigma_P^2 + (2(A^L - A^H) + r(-1+\delta)^2 \rho \sigma_P^2)^2}{4r^2(-1+\delta)^4 \rho^2 \sigma_P^4}} \\ \underline{k}_p \text{ and } \bar{k}_p &= \frac{2\bar{k}(L) - 1}{2} + \frac{\phi V^E}{r(1-\delta)^2 \rho \sigma_P^2} \\ &\quad \mp \sqrt{\frac{4\phi V^E(\phi V^E + 2A^L) + 4r\phi V^E(-1+\delta)(1+\delta-\rho + (-1+2n)\delta\rho)\sigma_P^2 + r^2(-1+\delta)^4 \rho^2 \sigma_P^4}{4r^2(-1+\delta)^4 \rho^2 \sigma_P^4}} \end{aligned}$$

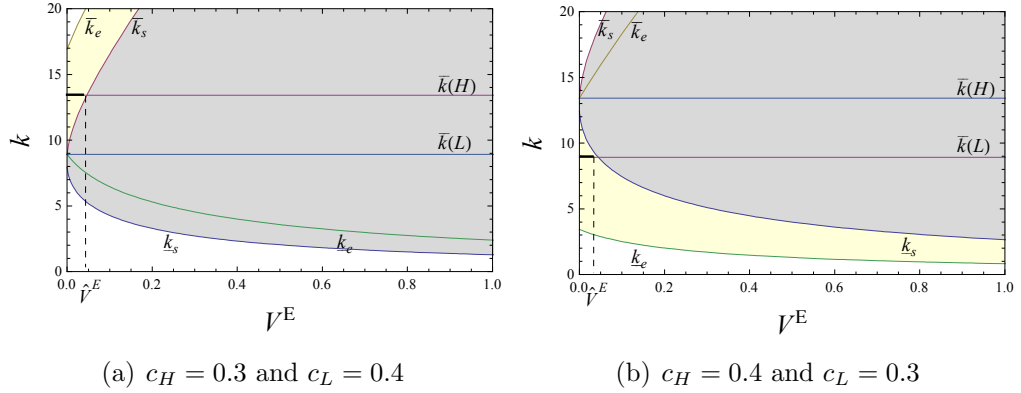


Figure 24: The most favorable situations for a high-type service provider in the presence of information asymmetry. Type can be successfully signaled through the full information strategy $\forall V^E \in [0, \hat{V}^E]$ for $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$ and $\rho = 0.46$.

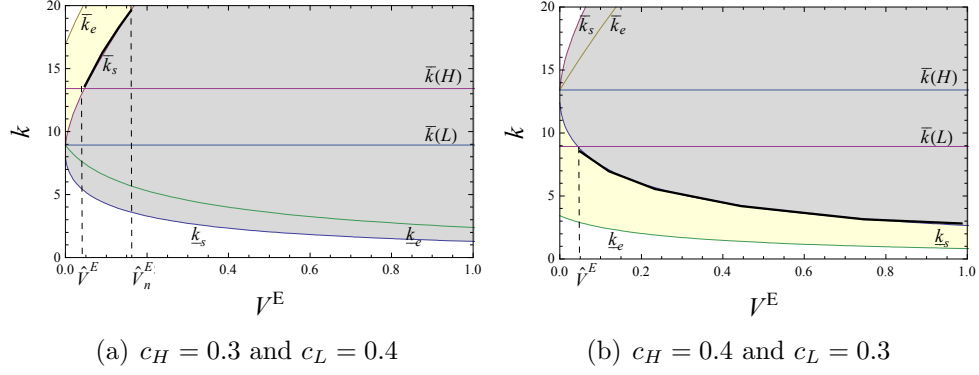


Figure 25: Signaling process efficiency through the control of more touchpoints (on the left) and expertise based outcome through the control of fewer touchpoints (on the right) when $V^E > \hat{V}^E$ and $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$, $\rho = 0.46$.

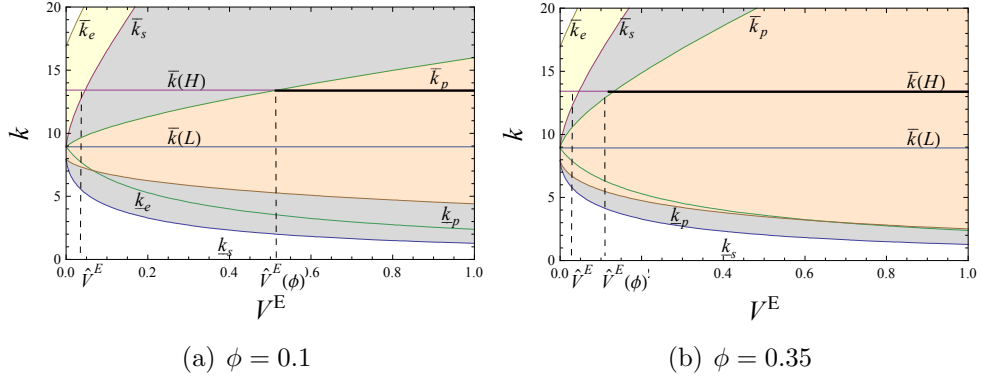


Figure 26: Pooling parabola and the existence of a pooling equilibrium when $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$, $\rho = 0.46$, $c_H = 0.3$, $c_L = 0.4$.

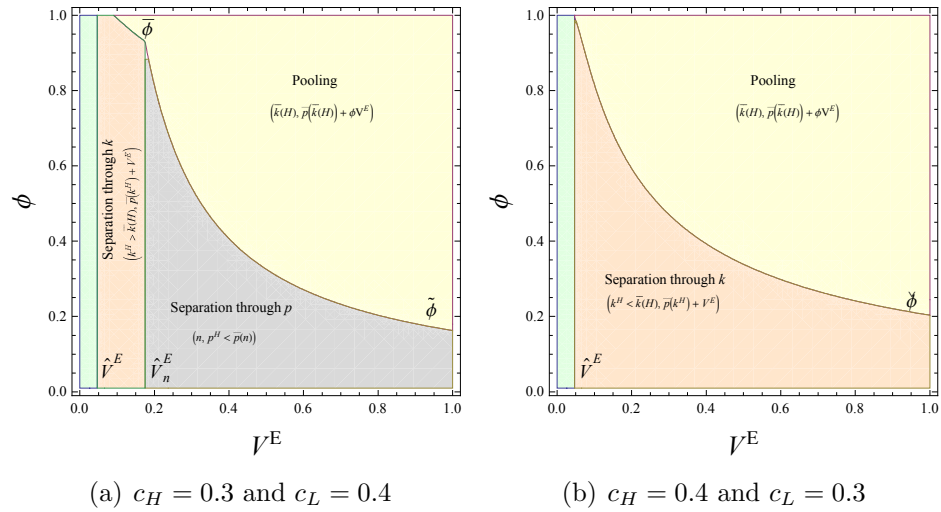


Figure 27: Optimal signaling strategies of the high-type service provider when $n = 20$, $r = 0.5$, $V^P = 2.26$, $V^C = 0.7$, $\sigma_P^2 = 0.31$, $\delta = 0.16$, $\rho = 0.46$.

Appendix B

B1. Table of Notation.

Table 5: Notation.

Parameters	Symbol	Units	Definition
	$\bar{a} = 1 - a$	(0,1)	Service level (vehicle availability) under <i>Membership</i> .
	D	Time Periods (e.g., years)	Vehicle Useful Life.
	T	Units of Time (e.g., hours)	Length of the Time Period.
	q	Total Vehicle Usage in a Time period (e.g., hours)	Total Time that a Customer Needs to Have a Vehicle "Off-Base."
	ξ	Times per Time Period	Total Number of Times a Customer Uses the Vehicle in a Given Time Period.
	$\bar{\lambda}$	Customers per Unit of Time	Compound Arrival Rate.
	$\bar{\tau}$	Time per Use (e.g., hours)	Expected Duration of Each Vehicle Use.
	$\Lambda(\cdot)$	$\bar{\lambda}\bar{\tau}$	Workload.
	ω	(0,1)	Fraction of the Usage Time that Operating Cost Accrues.
	h	(0,1)	Percentage of the Vehicle Production Cost Retained over D Periods.
	p_O	\$ per Unit of Usage Time	Vehicle Operating Cost (e.g., gas cost).
	c	\$	Vehicle Production Cost.
	$N = n_H + n_L$	Customers	Total Customer Population.
	y_i	\$	Transportation Budget of the i Segment.
	b	Usage Time (e.g., hours)/\$	Demand Slope Measuring the Change in Usage per Unit Change in Price.
Decision Variables		Units	Definition
	F_O	\$	Annualized Purchase Cost.
	F_M	\$	Yearly Membership Fee.
	p^M	\$ per Unit of Usage Time	Usage Price Under <i>Membership</i> .
	S	Vehicles	Number of Vehicles Offered Under <i>Membership</i> .

B2. Individual Rationality and Incentive Compatibility Constraints After the Introduction of *Membership*.

- (*Ownership, Ownership*): The High segment chooses *Ownership* and the Low segment chooses *Ownership*. In this case, constraints (29)-(31) need to hold (Figure 10(a)).

$$F_O \leq \bar{F}_{LO} = y_L - \omega p_O d \quad (29)$$

$$\bar{U}_{HO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{HM}} \bar{U}_{HM}^* \quad (30)$$

$$\bar{U}_{LO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{LM}} \bar{U}_{LM}^* \quad (31)$$

The individual rationality constraint of the high segment towards *Ownership* is trivially satisfied by the individual rationality constraint of the low segment.

- (*Membership, Membership*): The High segment chooses *Membership* and the Low segment chooses *Membership*. This case can exist if and only if constraints

(32)-(34) are satisfied (Figure 10(d)).

$$F_M \leq \bar{F}_{LM} = y_L - (p_M + (p_a - p_M) a) d \quad (32)$$

$$\bar{U}_{HM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{HO}} \bar{U}_{HO}^* \quad (33)$$

$$\bar{U}_{LM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{LO}} \bar{U}_{LO}^* \quad (34)$$

Once again the individual rationality constraint of the low segment satisfies the individual rationality constraint of the high segment too.

- (Membership, Ownership): The High segment chooses *Membership* and the Low segment chooses *Ownership*. This case can exist if and only if constraints (35)-(38) are satisfied.

$$F_M \leq \bar{F}_{HM} = y_H - (p_M + (p_a - p_M) a) d \quad (35)$$

$$F_O \leq \bar{F}_{LO} = y_L - \omega p_O d \quad (36)$$

$$\bar{U}_{HM}^* \geq \bar{U}_{HO}^* \quad (37)$$

$$\bar{U}_{LO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{LM}} \bar{U}_{LM}^* \quad (38)$$

- (Ownership, \emptyset): The High segment chooses *Ownership* and the Low segment does not participate. In this case, constraints (39)-(42) need to hold (Figure 10(b)).

$$F_O \leq \bar{F}_{HO} = y_H - \omega p_O d \quad (39)$$

$$\bar{U}_{HO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{HM}} \bar{U}_{HM}^* \quad (40)$$

$$F_M > \bar{F}_{LM} = y_L - (p_M + (p_a - p_M) a) d \quad (41)$$

$$F_O > \bar{F}_{LO} = y_L - \omega p_O d \quad (42)$$

- (Membership, \emptyset): The High segment chooses *Membership* and the Low segment does not participate. This case can exist if and only if constraints (43)-(46) are

satisfied.

$$F_M \leq \bar{F}_{HM} = y_H - (p_M + (p_a - p_M) a) d \quad (43)$$

$$\bar{U}_{HM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{HO}} \bar{U}_{HO}^* \quad (44)$$

$$F_M > \bar{F}_{LM} = y_L - (p_M + (p_a - p_M) a) d \quad (45)$$

$$F_O > \bar{F}_{LO} = y_L - \omega p_O d \quad (46)$$

- (\emptyset, \emptyset) : None of the segments participates. Constraints (47)-(48) need to hold.

$$F_M > \bar{F}_{HM} = y_H - (p_M + (p_a - p_M) a) d \quad (47)$$

$$F_O > \bar{F}_{HO} = y_H - \omega p_O d \quad (48)$$

B3. The Manufacturer's Maximization Problem Under Different Market Configurations.

- Ownership, Ownership: The High segment chooses *Ownership* and the Low segment chooses *Ownership*.

$$\max_{F_O, F_M, p_M \geq 0} \Pi = (DF_O - (1 - h)c) (n_H + n_L)$$

$$s.t \ F_O \leq y_L - \omega p_O d$$

$$\bar{U}_{HO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{HM}} \bar{U}_{HM}^*$$

$$\bar{U}_{LO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{LM}} \bar{U}_{LM}^*$$

- Membership, Membership: The High segment chooses *Membership* and the Low

segment chooses *Membership*.

$$\begin{aligned}
\max_{F_O, F_M, p_M \geq 0} \quad & \Pi = (n_H + n_L) D (F_M + (p_M - \omega p_O) \bar{a} q_M^*) - (1 - h) c S \\
s.t \quad & S = \left(\frac{q_M^* n^M}{T} + z_{\bar{a}} \sqrt{\frac{q_M^* n^M}{T}} \right) \\
& F_M \leq y_L - (p_M + (p_a - p_M) a) d \\
& \bar{\mathcal{U}}_{HM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{HO}} \bar{\mathcal{U}}_{HO}^* \\
& \bar{\mathcal{U}}_{LM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{LO}} \bar{\mathcal{U}}_{LO}^*
\end{aligned}$$

with $q_M^* = \frac{n_H}{n_H + n_L} q_{HM}^* + \frac{n_L}{n_H + n_L} q_{LM}^*$ and $n^M = n_L + n_H$.

- *Membership, Ownership*: The High segment chooses *Membership* and the Low segment chooses *Ownership*.

$$\begin{aligned}
\max_{F_O, F_M, p_M \geq 0} \quad & \Pi = (D F_O - (1 - h) c) n_L + n_H D (F_M + (p_M - \omega p_O) \bar{a} q_{HM}^*) - (1 - h) c S \\
s.t \quad & S = \left(\frac{q_{HM}^* n_H}{T} + z_{\bar{a}} \sqrt{\frac{q_{HM}^* n_H}{T}} \right) \\
& F_M \leq y_H - (p_M + (p_a - p_M) a) d \\
& F_O \leq y_L - \omega p_O d \\
& \bar{\mathcal{U}}_{HM}^* \geq \bar{\mathcal{U}}_{HO}^* \\
& \bar{\mathcal{U}}_{LO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{LM}} \bar{\mathcal{U}}_{LM}^*
\end{aligned}$$

- *Ownership, \emptyset* : The High segment chooses *Ownership* and the Low segment does not participate.

$$\begin{aligned}
\max_{F_O, F_M, p_M \geq 0} \quad & \Pi = (D F_O - (1 - h) c) n_H \\
s.t \quad & F_O \leq y_H - \omega p_O d \\
& \bar{\mathcal{U}}_{HO}^* \geq \mathbf{1}_{F_M \leq \bar{F}_{HM}} \bar{\mathcal{U}}_{HM}^* \\
& F_M > y_L - (p_M + (p_a - p_M) a) d \\
& F_O > y_L - \omega p_O d
\end{aligned}$$

- Membership, \emptyset : The High segment chooses *Membership* and the Low segment does not participate.

$$\begin{aligned}
\max_{F_O, F_M, p_M \geq 0} \quad & \Pi = n_H D \left(F_M + (p_M - \omega p_O) \bar{a} q_{HM}^* \right) - (1 - h) c S \\
s.t \quad & S = \left(\frac{q_{HM}^* n_H}{T} + z_{\bar{a}} \sqrt{\frac{q_{HM}^* n_H}{T}} \right) \\
& F_M \leq y_H - (p_M + (p_a - p_M) a) d \\
& \bar{\mathcal{U}}_{HM}^* \geq \mathbf{1}_{F_O \leq \bar{F}_{HO}} \bar{\mathcal{U}}_{HO}^* \\
& F_M > y_L - (p_M + (p_a - p_M) a) d \\
& F_O > y_L - \omega p_O d
\end{aligned}$$

- \emptyset, \emptyset : None of the segments participates.

$$\begin{aligned}
& F_M > y_H - (p_M + (p_a - p_M) a) d \\
& F_O > y_H - \omega p_O d
\end{aligned}$$

B4. Proofs.

Proof of Lemma 2. The prerequisite is met if and only if $\bar{q}_{ij} \geq d$, which is simplified to $F_j \leq y_i - (p_j + (p_a - p_j) a_j) \omega_{ij} d \doteq \bar{F}_{ij}$. \square

Proof of Proposition 1. Define the unconstrained maximizer of (5) by equation (49) and the usage q_{ij} that exhausts the budget constraint (7) by equation (50).

$$\begin{aligned}
\tilde{q}_{ij} & \doteq \left\{ q_{ij} : \frac{d\bar{\mathcal{U}}_{ij}(q_{ij})}{dq_{ij}} = 0 \right\} \\
& = \bar{d} - b(p_j + (p_a - p_j) a_j) \omega_j
\end{aligned} \tag{49}$$

$$\begin{aligned}
\bar{q}_{ij} & \doteq \{ q_{ij} : y_i = \mathcal{C}_j(q_{ij}) \} \\
& = \frac{y_i - F_j}{(p_j + (p_a - p_j) a_j) \omega_j}
\end{aligned} \tag{50}$$

For all $F_j \leq \bar{F}_{ij}$, the optimization problem (5) can be restated as

$$\begin{aligned} \max_{q_{ij}} \quad & \bar{\mathcal{U}}_{ij} = y_i + \mathcal{U}_{ij}(q_{ij}) - \mathcal{C}_j(q_{ij}) \\ \text{s.t.} \quad & q_{ij} \geq d \\ & q_{ij} \leq \bar{q}_{ij} \end{aligned} \quad (51)$$

The Lagrangean of (51) is given by (52).

$$\begin{aligned} \mathcal{L} &= y_i + \mathcal{U}_{ij}(q_{ij}) - \mathcal{C}_j(q_{ij}) + \mu_1 (q_{ij} - d) - \mu_2 (q_{ij} - \bar{q}_{ij}) \\ &= y_i + \frac{1}{b} \left(\bar{d}q_{ij} - \frac{q_{ij}^2}{2} \right) + \gamma_j - F_j - \left(p_j + (p_a - p_j) a_j \right) \omega_j q_{ij} + \mu_1 (q_{ij} - d) - \mu_2 (q_{ij} - \bar{q}_{ij}) \end{aligned} \quad (52)$$

with the the first-order condition given by (53).

$$\begin{aligned} \frac{d\mathcal{L}}{dq_{ij}} &= \frac{\bar{d} - q_{ij}}{b} - \left(p_j + (p_a - p_j) a_j \right) \omega_j + \mu_1 - \mu_2 \\ &= \frac{\tilde{q}_{ij} - q_{ij}}{b} + \mu_1 - \mu_2 = 0 \end{aligned} \quad (53)$$

Since (5) is strictly concave in q_{ij} ($\frac{d^2 \bar{\mathcal{U}}_{ij}(q_{ij})}{d^2 q_{ij}} = -\frac{1}{b}$), the necessary and sufficient conditions for optimality (Kuhn-Tucker conditions) are that the first-order condition (53) is satisfied and $\mu_1 (q_{ij} - d) = 0$, $\mu_2 (q_{ij} - \bar{q}_{ij}) = 0$, $\mu_1 \geq 0$ and $\mu_2 \geq 0$. There are three candidate solutions to (51):

I. $q_{ij} = d$. Then $\mu_1 > 0$ and $\mu_2 = 0$ which hold for

$$\begin{aligned} d &> \tilde{q}_{ij} \Leftrightarrow \\ \bar{d} &< d + b(p_j + (p_a - p_j)a_j)\omega_{ij}. \end{aligned} \quad (54)$$

II. $q_{ij} = \bar{q}_{ij}$. Then $\mu_2 > 0$ and $\mu_1 = 0$ which hold for

$$\begin{aligned} \tilde{q}_{ij} &> \bar{q}_{ij} \Leftrightarrow \\ \bar{d} &> b(p_j + (p_a - p_j)a_j)\omega_j + \frac{y_i - F_j}{(p_j + (p_a - p_j)a_j)\omega_j}. \end{aligned} \quad (55)$$

III. $q_{ij} = \tilde{q}_{ij} \in (d, \bar{q}_{ij})$. Then $\mu_1 = 0$ and $\mu_2 = 0$ which hold for

$$b(p_j + (p_a - p_j)a_j)\omega_j + \frac{y_i - F_j}{(p_j + (p_a - p_j)a_j)\omega_j} < \bar{d} < d + b(p_j + (p_a - p_j)a_j)\omega_j \quad (56)$$

Without imposing any restrictive assumptions on the parameters we can express q_{ij}^* compactly as in (57).

$$q_{ij}^* = \min\{\max\{\tilde{q}_{ij}, d\}, \bar{q}_{ij}\}. \square \quad (57)$$

Proof of Proposition 2. The optimal usage q_{ij}^* is nondecreasing in y_i . Furthermore, for $F_j > 0$ and $y_i = 0$ none of the segments can participate in *Ownership* or *Membership*. Therefore, it suffices to show that

$$\begin{aligned} \frac{d\bar{q}_{iO}}{dy_i} &> \frac{d\bar{q}_{iM}}{dy_i} \Leftrightarrow \\ \frac{1}{p_{OW}} &> \frac{1}{a(p_a - p_M) + p_M} \Leftrightarrow \\ p_M &> \frac{p_{OW} - ap_a}{1 - a} \doteq \hat{p}_M. \end{aligned} \quad (58)$$

If (58) holds, then a unique crossing point \bar{y}_i is guaranteed to exist such that $q_{iO}^* > q_{iM}^*$ for every $y_i > \bar{y}_i$. \square

Proof of Proposition 3. Since q_{iM}^* is nonincreasing in p_M and q_{iO}^* is independent of p_M , it suffices to establish that $q_{iM}^*(p_M = 0) > q_{iO}^*$. The cases in Proposition 3 correspond to the following scenarios:

- I. $q_{iM}^*(p_M = 0) = d$ and $q_{iO}^* < q_{iM}^*(p_M = 0)$.
- II. $q_{iM}^*(p_M = 0) = \bar{d} - abp_a$ and $q_{iO}^* < q_{iM}^*(p_M = 0)$.
- III. $q_{iM}^*(p_M = 0) = \frac{y_i - F_M}{ap_a}$ and $q_{iO}^* < q_{iM}^*(p_M = 0)$.

If any of the above cases holds, then a unique crossing point \bar{p}_M is guaranteed to exist such that $q_{iM}^* > q_{iO}^*$ for every $p_M < \bar{p}_M$. \square

Proof of Lemma 3. Under the first option the manufacturer sets $F_O = \bar{F}_{HO}$ and extracts $\Pi^O = ((y_H - \omega p_O d) D - (1 - h)c)n_H$, while under the second option she sets

$F_O = \bar{F}_{LO}$ and extracts $\Pi^O = ((y_L - \omega p_{Od})D - (1 - h)c)(n_H + n_L)$. By a simple comparison of the two profits we see that selling to both segments is more profitable if and only if (59) and (60) hold together.

$$n_L > \frac{n_H D (y_H - y_L)}{(y_L - \omega p_{Od})D - c(1 - h)} \doteq \tilde{n}_L \quad (59)$$

$$y_L > \omega p_{Od} + \frac{(1 - h)c}{D} \doteq \tilde{y}_L. \square \quad (60)$$

B5. Estimation of the Parameters.

In what follows we provide details regarding the sources and methods we used for the calculation of our parameters.

- D: Vehicle Useful Life.

According to Santos et al. (2011) almost 60% of the household vehicles in the US are less than 10 years old (see category “Auto” in Figure 28). The American

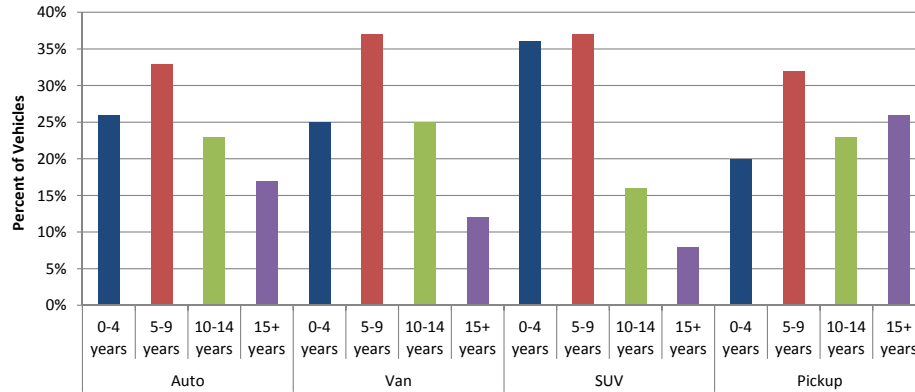


Figure 28: Household vehicles by type and age (adapted by Santos et al., 2011).

Automobile Association (2011) and Binder (2010) assume, respectively, a 5 and 6 year useful vehicle lifetime to calculate car ownership costs. Given the fleet composition of Zipcar (in terms of production year), a vehicle lifetime greater than five years is rather unrealistic for our setting. Therefore, we use $D = 5$ years.

- c: Vehicle Production Cost.

Information regarding the production cost of auto manufacturers is rarely publicly available. Therefore, we use a combination of different sources. Specifically, using the wrds-Wharton Research Data Services, we extract data regarding the Cost of Goods Sold (COGS) for Ford and Toyota during the periods 2008-2009 and 2007-2008, respectively, while from Binder (2010) we obtain the corresponding Worldwide Wholesale Sales (WWS). In Table 6 we calculate the vehicle production cost as $c = COGS/WWS$.

Table 6: Estimation of the vehicle production cost.

Company	Year	Revenue	COGS	WWS	Revenue/COGS	COGS/WWS
Ford	2008	\$146,277,000,000	\$115,883,000,000	5,399,000	1.26	\$21,464
Ford	2009	\$118,308,000,000	\$95,836,000,000	4,817,000	1.23	\$19,895
Toyota	2007	\$262,394,000,000	\$199,912,000,000	8,913,000	1.31	\$22,429
Toyota	2008	\$208,995,000,000	\$172,663,000,000	7,567,000	1.21	\$22,818

To account for the fact that the above data aggregate a variety of vehicle types and models we use a wider range of production costs, that is $c = \{\$15 \times 10^3, \$22.5 \times 10^3, \$25 \times 10^3\}$.

- h \in (0,1): Percent of the Vehicle Production Cost Retained over D Periods.

In order to estimate h we use data from the American Automobile Association (2011) for the period 2005-2011. Table 7 indicates the ownership cost that the American Automobile Association (2011) estimated for the years 2005-2011. The vehicle depreciation cost is based on the difference between, the new vehicle selling price and the trade-in value at the end of five years. The finance charge is based on a five year loan at 6% interest with a 10% down payment. Using this information, in Table 8 we calculate the average vehicle selling prices that correspond to each vehicle type of Table 7. For instance, according to Table 7, in 2011 the finance charge for a small sedan was \$584. We use the CUMIPMT function of Excel to calculate the finance charge that corresponds to a five year loan at 6% interest with a 10% *Selling Price* down payment. With the help of

Solver we are able to calculate the *Selling Price* that sets to zero the difference between the output of CUMIPMT and \$584. The resulting selling price is \$20,282. Building on the calculation of the average selling prices and assuming straight line depreciation, we also estimate $h' \in (0, 1)$, which represents the value that the vehicle retains after five years as a percent of the *selling price* (i.e., $R = h' \text{Selling Price}$). Using the same example, from Table 7 we see that in 2011 the depreciation cost over a five year period for a small sedan was \$2,560. Therefore, $h' = \frac{20,282 - 5 \times 2,560}{20,282} = 0.37$.

In our model, the resale value is expressed as a fraction of the production cost, that is, $R = hc$. Therefore, $h = h' \frac{\text{Selling Price}}{c} = h' \frac{\text{Revenue}}{\text{COGS}}$ (see Table 6 for the values of *Revenue/COGS*). By trying different combinations of h' and *Revenue/COGS* we find that the values $h = \{0.3, 0.4, 0.5\}$ are realistic representations of the percentage of the vehicle production cost that is retained by the end of a five year period.

- **p_O**: Vehicle Operating Cost.

Once again, we use data from the American Automobile Association (2011) for the period 2005-2011. Table 9 shows the vehicle operating costs that the American Automobile Association (2011) estimated for the years 2005-2011.

However, the costs shown in Table 9 are expressed in ¢/mile. In our model, vehicle usage is expressed in units of time; therefore, it is necessary to convert the operating costs from ¢/mile to \$/hour. We perform this conversion by assuming an average driving speed of 30 miles/hour, which is a typical assumption in transportation studies (Frost & Sullivan, 2010; Santos et al., 2011). Table 10 exhibits some of the descriptive statistics of the vehicle operating costs during 2005-2011 expressed in \$/hour. The values range from as low as 3.63\$/hour to as high as 6.05\$/hour. To account for different driving styles and within-year

Table 7: Vehicle ownership costs.

Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$951	\$948	\$1,006	\$968
0	License, registration, taxes	\$438	\$577	\$769	\$595
1	Depreciation (15,000 miles annually)	\$2,560	\$3,534	\$5,091	\$3,728
1	Finance charge	\$584	\$796	\$1,089	\$823
		\$4,533	\$5,855	\$7,955	\$6,114
Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$1,005	\$1,004	\$1,084	\$1,031
0	License, registration, taxes	\$427	\$583	\$745	\$585
1	Depreciation (15,000 miles annually)	\$2,384	\$3,451	\$4,828	\$3,554
0	Finance charge	\$565	\$803	\$1,050	\$806
		\$4,381	\$5,841	\$7,707	\$5,976
Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$948	\$957	\$1,022	\$976
0	License, registration, taxes	\$419	\$572	\$711	\$567
0	Depreciation (15,000 miles annually)	\$2,430	\$3,401	\$4,554	\$3,462
9	Finance charge	\$553	\$786	\$998	\$779
		\$4,350	\$5,716	\$7,285	\$5,784
Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$949	\$907	\$973	\$943
0	License, registration, taxes	\$410	\$562	\$690	\$554
0	Depreciation (15,000 miles annually)	\$2,332	\$3,355	\$4,275	\$3,321
8	Finance charge	\$541	\$770	\$963	\$758
		\$4,232	\$5,594	\$6,901	\$5,576
Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$968	\$955	\$1,032	\$985
0	License, registration, taxes	\$401	\$544	\$668	\$538
0	Depreciation (15,000 miles annually)	\$2,461	\$3,394	\$4,321	\$3,392
7	Finance charge	\$527	\$743	\$929	\$733
		\$4,357	\$5,636	\$6,950	\$5,648
Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$892	\$902	\$982	\$925
0	License, registration, taxes	\$397	\$551	\$658	\$535
0	Depreciation (15,000 miles annually)	\$2,503	\$3,449	\$4,224	\$3,392
6	Finance charge	\$511	\$739	\$899	\$716
		\$4,303	\$5,641	\$6,763	\$5,569
Ownership Costs (\$/mile)		Small Sedan	Medium Sedan	Large Sedan	Average
2	Full-coverage insurance	\$1,456	\$1,195	\$1,212	\$1,288
0	License, registration, taxes	\$333	\$390	\$445	\$389
0	Depreciation (15,000 miles annually)	\$2,985	\$4,005	\$4,647	\$3,879
5	Finance charge	\$553	\$740	\$925	\$739
		\$5,327	\$6,330	\$7,229	\$6,295

gasoline price volatility, we use a wider range, that is $p_O = \{4, 6.5, 9\}$ \$/hour.

- **p_a**: Cost of not Finding a Vehicle Available.

We assume that every time customers cannot find a vehicle available they resort to alternative modes of transportation such as taxicabs. Therefore, in order to estimate p_a we collect data regarding typical taxicab fares. Based on information acquired from Schaller Consulting (2006), we construct Table 11 which shows taxicab fares (in terms of \$/trip) in major US cities.⁵ Assuming an average driving speed of 30 miles/hour we convert the \$/trip fares of Table 11 into

⁵In Table 11, *Average US Trip* refers to 5 miles and 5 minutes of wait time or 0.17 hours assuming 30 miles/hour, *Short Trip* refers to 2.8 miles and 4.77 minutes of wait time or 0.09 hours assuming 30 miles/hour, and *Long Trip* refers to 12 miles and 5 minutes of wait time or 0.40 hours assuming 30 miles/hour (Schaller Consulting, 2006).

Table 8: Estimation of the average selling price and the percent of it retained after five years.

2011	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$20,282	\$27,644	\$37,820	\$28,582
h'	0.37	0.36	0.33	0.35
2010	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$19,622	\$27,888	\$36,466	\$27,992
h'	0.39	0.38	0.34	0.37
2009	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$19,205	\$27,297	\$34,660	\$27,054
h'	0.37	0.38	0.34	0.36
2008	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$18,788	\$26,741	\$33,444	\$26,325
h'	0.38	0.37	0.36	0.37
2007	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$18,302	\$25,804	\$32,263	\$25,456
h'	0.33	0.34	0.33	0.33
2006	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$17,747	\$25,665	\$31,222	\$24,878
h'	0.29	0.33	0.32	0.32
2005	Small Sedan	Medium Sedan	Large Sedan	Average
Average Selling Price	\$19,205	\$25,700	\$32,124	\$25,676
h'	0.22	0.22	0.28	0.24

\$/hour fares which we show in Table 12. The values in Table 12 range from as low as 54.95\$/hour to as high as 144.89\$/hour. We choose the average values to estimate $p_a = \{69.80\omega, 81.46\omega, 104.6\omega\}$ \$/hour.⁶

- **b: Demand Slope Measuring the Change in Usage per Unit Change in Price.**

With respect to b , in Table 13 we utilize information regarding the Average Annual Miles Traveled per Vehicle during 2008-2005 from Binder (2010) and the corresponding average operating costs from Table 9. A simple linear regression between the Average Annual Hours Traveled per Vehicle and the Average Operating Cost (\$/hour) reveals that $b = 26.6$ (see Figure 29). Therefore, we choose to use $b = \{15, 25, 35\}$ hours/\$.

We can arrive to similar estimations by adopting a slightly different approach

⁶We include the parameter ω because taxicab charges accrue with the *actual* driving time/distance. That is, the values of p_a may actually differ across different driving profiles.

Table 9: Vehicle operating costs.

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	10.05	12.82	14.16	12.34
0	Maintenance	4.11	4.29	4.93	4.44
1	Tires	0.67	1.11	1.09	0.96
1		14.83	18.22	20.18	17.74

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	9.24	11.97	12.88	11.36
0	Maintenance	4.21	4.42	5.00	4.54
1	Tires	0.65	0.91	0.94	0.83
0		14.10	17.30	18.82	16.74

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	8.21	10.54	11.51	10.09
0	Maintenance	4.26	4.51	4.92	4.56
0	Tires	0.61	0.87	0.82	0.77
9		13.08	15.92	17.25	15.42

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	9.39	12.34	13.28	11.67
0	Maintenance	3.98	4.67	5.07	4.57
0	Tires	0.55	0.85	0.77	0.72
8		13.92	17.86	19.12	16.97

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	7.40	9.40	10.00	8.93
0	Maintenance	4.50	4.70	5.50	4.90
0	Tires	0.50	0.80	0.70	0.67
7		12.40	14.90	16.20	14.50

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	8.00	9.80	10.70	9.50
0	Maintenance	4.50	4.90	5.40	4.93
0	Tires	0.50	0.80	0.70	0.67
6		13.00	15.50	16.80	15.10

	Operating Costs (¢/mile)	Small Sedan	Medium Sedan	Large Sedan	Average
2	Gas	6.90	8.50	9.30	8.23
0	Maintenance	4.70	5.80	5.40	5.30
0	Tires	0.50	0.70	0.50	0.57
5		12.10	15.00	15.20	14.10

that involves the price elasticity of gasoline demand. Specifically, the price (p_t) elasticity of the demand (d_t) at period t is calculated as $\varepsilon_t = \frac{\partial d_t}{\partial p_t} \frac{p_t}{d_t}$. Assuming linear demand function, $d_t = a - bp_t$, we obtain $\frac{\partial d_t}{\partial p_t} = -b$ and therefore, $b = -\frac{d_t}{p_t} \varepsilon_t$. If we set $\varepsilon_t = -0.34$, which is the short run price elasticity calculated by Brons et al. (2008) and for different values of $\frac{d_t}{p_t}$ use the 2006-2008 values for the Average Annual Hours Traveled per Vehicle and the Average Operating Cost (\$/hour) found in Table 13, then we obtain values for b that range from 26.25 to 32.02. Therefore, b can still be realistically represented by the set $\{15, 25, 35\}$ hours/\$.

Table 10: Descriptive statistics of vehicle operating costs in \$/hour.

MIN-Operating Costs (\$/hour)	Small Sedan	Medium Sedan	Large Sedan	Average
Gas	\$2.07	\$2.55	\$2.79	\$2.47
Maintenance	\$1.19	\$1.29	\$1.48	\$1.33
Tires	\$0.15	\$0.21	\$0.15	\$0.17
	\$3.63	\$4.47	\$4.56	\$4.23
Median-Operating Costs (\$/hour)	Small Sedan	Medium Sedan	Large Sedan	Average
Gas	\$2.46	\$3.16	\$3.45	\$3.03
Maintenance	\$1.28	\$1.40	\$1.52	\$1.37
Tires	\$0.17	\$0.26	\$0.23	\$0.22
	\$3.92	\$4.78	\$5.18	\$4.63
Mean-Operating Costs (\$/hour)	Small Sedan	Medium Sedan	Large Sedan	Average
Gas	\$2.54	\$3.23	\$3.51	\$3.09
Maintenance	\$1.30	\$1.43	\$1.55	\$1.43
Tires	\$0.17	\$0.26	\$0.24	\$0.22
	\$4.00	\$4.92	\$5.30	\$4.74
MAX-Operating Costs (\$/hour)	Small Sedan	Medium Sedan	Large Sedan	Average
Gas	\$3.02	\$3.85	\$4.25	\$3.70
Maintenance	\$1.41	\$1.74	\$1.65	\$1.59
Tires	\$0.20	\$0.33	\$0.33	\$0.29
	\$4.45	\$5.47	\$6.05	\$5.32

- $y_i \forall i \in \{\mathbf{H}, \mathbf{L}\}$: Transportation Budget of the i Segment.

As reported by the Bureau of Labor Statistics (2011), households in the US spend approximately 13% of their income on transportation (see Table 4.4). We use this observation in conjunction with the US income distribution as found in Proctor (2011) and we construct Table 15. In Table 15, we multiply 13% by the median income of each bracket to calculate the transportation budget of the respective income bracket. Cervero et al. (2007) survey car share users whose median income is \$50,000. We focus on a broader customer base by focusing on the C, D, E, and F brackets. Specifically, we use $(y_H, y_L) = \{(\$5.525 \times 10^3, \$3.900 \times 10^3), (\$8.125 \times 10^3, \$5.525 \times 10^3), (\$11.375 \times 10^3, \$8.125 \times 10^3)\}$.

- $n_i \forall i \in \{\mathbf{H}, \mathbf{L}\}$: Customer Population in the i Segment.

From Table 15 we can also see that $n_D/n_C = 1.28$, $n_E/n_D = 1.27$, and $n_F/n_E = 0.64$. Therefore, we representatively choose $n_H/n_L = \{1.50, 0.75\}$. Regarding the estimation of the total customer population $N = n_H + n_L$, we

Table 11: Taxicab fares for typical trips in major US cities (\$/trip).

City	Average US Trip	Short Trip	Long Trip
Honolulu	\$19.75	\$13.04	\$40.75
San Diego	\$16.17	\$10.59	\$33.67
Miami	\$16.10	\$10.73	\$32.90
San Francisco	\$15.90	\$10.85	\$31.65
Boston	\$15.45	\$10.08	\$32.25
Los Angeles	\$15.00	\$10.07	\$30.40
Seattle	\$14.80	\$10.29	\$28.80
Las Vegas	\$14.75	\$10.27	\$28.75
St. Louis	\$14.30	\$9.81	\$28.30
Philadelphia	\$14.17	\$9.47	\$28.87
Atlanta	\$14.00	\$9.52	\$28.00
Orlando	\$13.38	\$8.89	\$27.38
Minneapolis	\$13.37	\$9.11	\$26.67
Denver	\$13.23	\$8.74	\$27.23
New York	\$13.10	\$8.65	\$27.10
Phoenix	\$12.87	\$8.83	\$27.10
Houston	\$12.85	\$8.81	\$25.45
Chicago	\$12.70	\$8.66	\$25.30
DC Suburbs	\$12.08	\$8.35	\$23.70
Dallas	\$12.55	\$8.52	\$25.15
New Orleans	\$11.80	\$8.21	\$23.00
Detroit	\$11.65	\$8.07	\$22.85
Baltimore	\$11.60	\$7.99	\$22.80
Cleveland	\$10.78	\$7.21	\$21.98

proceed by first estimating the geographic area that Zipcar covers through its car sharing fleet in the greater Midtown area in Atlanta, Fulton County, GA. From Figures (30(a)) and (30(b)) we can approximate this area as 2.81 sq. miles. According to the Georgia Department of Labor (2006) the population density of Fulton County is 1,796 people/sq. mile, hence we can easily calculate the total customer population as approximately $N = n_H + n_L = 5,000$. Combining our estimations regarding, n_H/n_L and $n_H + n_L$ it is straightforward to establish the use of $(n_H, n_L) = \{(2.807 \times 10^3, 1.951 \times 10^3), (2.193 \times 10^3, 3.049 \times 10^3)\}$. It is worth mentioning that, *ceteris paribus*, the manufacturer's optimal decisions will remain the same for different values of N . Specifically, it is the relative size of the segments that influences the manufacturer's decisions as opposed to the total size N of the market.

Table 12: Taxicab fares for typical trips in major US cities (\$/hour).

City	Average US Trip	Short Trip	Long Trip
Honolulu	\$116.18	\$144.89	\$101.88
San Diego	\$95.12	\$117.67	\$84.18
Miami	\$94.71	\$119.22	\$82.25
San Francisco	\$93.53	\$120.56	\$79.13
Boston	\$90.88	\$112.00	\$80.63
Los Angeles	\$88.24	\$111.89	\$76.00
Seattle	\$87.06	\$114.33	\$72.00
Las Vegas	\$86.76	\$114.11	\$71.88
St. Louis	\$84.12	\$109.00	\$70.75
Philadelphia	\$83.35	\$105.22	\$72.18
Atlanta	\$82.35	\$105.78	\$70.00
Orlando	\$78.71	\$98.78	\$68.45
Minneapolis	\$78.65	\$101.22	\$66.68
Denver	\$77.82	\$97.11	\$68.08
New York	\$77.06	\$96.11	\$67.75
Phoenix	\$75.71	\$98.11	\$67.75
Houston	\$75.59	\$97.89	\$63.63
Chicago	\$74.71	\$96.22	\$63.25
DC Suburbs	\$71.06	\$92.78	\$59.25
Dallas	\$73.82	\$94.67	\$62.88
New Orleans	\$69.41	\$91.22	\$57.50
Detroit	\$68.53	\$89.67	\$57.13
Baltimore	\$68.24	\$88.78	\$57.00
Cleveland	\$63.41	\$80.11	\$54.95
Average	\$81.46	\$104.06	\$69.80

Table 13: Annual miles and hours traveled per vehicle with respect to the average operating cost.

Year	Average Annual Miles Traveled per Vehicle	Average Annual Hours Traveled per Vehicle (30miles/hour)	Average Operating Cost (\$/mile)	Average Operating Cost (\$/hour)
2008	11,788	393	0.17	5.09
2007	12,293	410	0.15	4.35
2006	12,427	414	0.15	4.53
2005	12,510	417	0.14	4.23

- F_M : Annual Membership Fee.

In order to estimate F_M we survey the membership fees charged by various car sharing providers. In Table 16, we see that F_M can be as low as \$0 and as high as \$360 (multiple values of F_M for the same provider are associated with the different value plans offered by the specific provider). We choose $F_M = \{\$50, \$150, \$250\}$ as a representative range of annual membership fees.

- \bar{a} : Service Level (Vehicle Availability) Under Membership.

Since no data regarding the availability of the car sharing vehicles are publicly available, we choose a relatively wide range $\bar{a} = \{90\%, 95\%, 98\%\}$. We consider

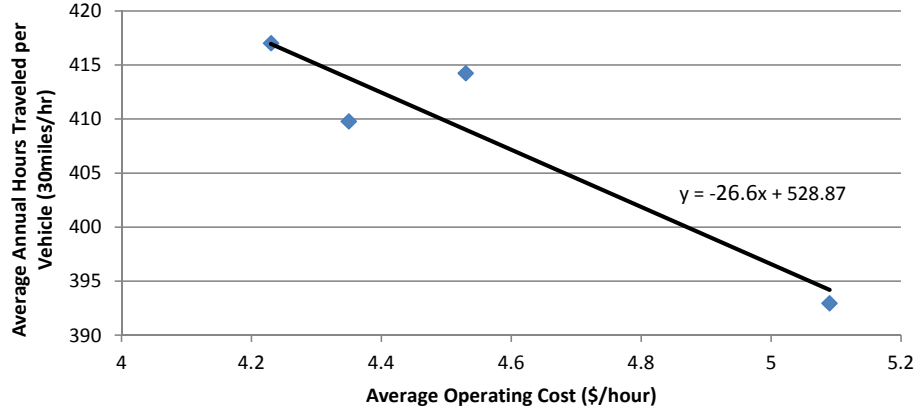


Figure 29: Annual hours traveled per vehicle with respect to the average operating cost.

Table 14: Average annual household expenditures and income.

	2008	2009	2010
Income before taxes	\$63,563	\$62,857	\$62,481
Average annual expenditures	\$50,486	\$49,067	\$48,109
Food	\$6,443	\$6,372	\$6,129
Housing	\$17,109	\$16,895	\$16,557
Apparel and Services	\$1,801	\$1,725	\$1,700
Transportation	\$8,604	\$7,685	\$7,677
Healthcare	\$2,976	\$3,126	\$3,157
Entertainment	\$2,835	\$2,693	\$2,504
Cash contributions	\$1,737	\$1,723	\$1,633
Personal insurance and pensions	\$5,605	\$5,471	\$5,373
All other expenditures	\$3,376	\$3,404	\$3,379

any values outside this range rather unrealistic. Specifically, for service levels below 90%, *Membership* cannot be regarded as a viable alternative to *Ownership*, while service levels above 98% essentially imply no “stockouts” (refer to Frei (2005) for evidence to the contrary).

- $\gamma_j \forall j \in \{\mathbf{O}, \mathbf{M}\}$: Intrinsic Preference to Own or be a Member.

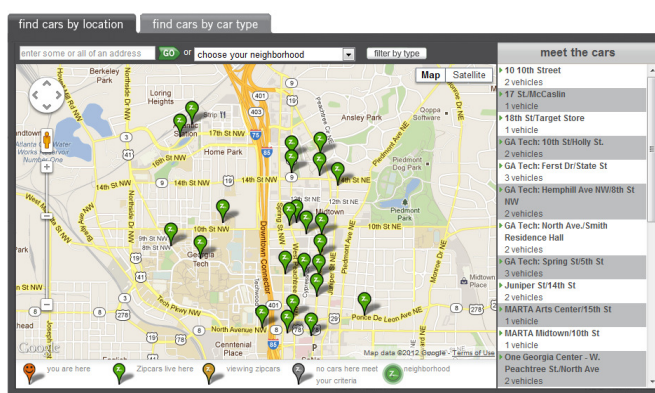
We choose to focus on the purely economic drivers (as opposed to behavioral drivers; e.g., endowment effect or environmental consciousness) that shape customers’ transportation choices. For that reason we set $(\gamma_O, \gamma_M) = (0, 0)$.

Table 15: Income distribution in 2010.

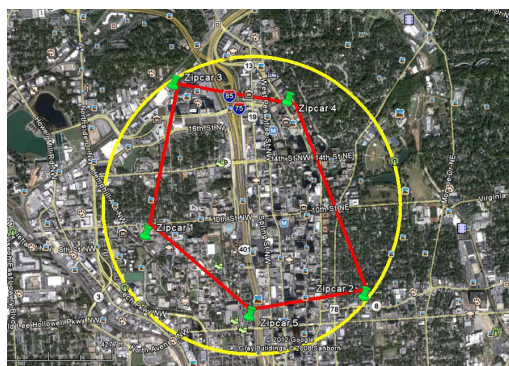
	A	B	C	D	E	F	G	H	I
	Under \$15,000	\$15,000 to \$24,999	\$25,000 to \$34,999	\$35,000 to \$49,999	\$50,000 to \$74,999	\$75,000 to \$99,999	\$100,000 to \$149,999	\$150,000 to \$199,999	\$200,000+
Percent of Population	13.70%	12%	10.90%	13.90%	17.70%	11.40%	12.10%	4.50%	3.90%
Median Income		\$20,000	\$30,000	\$42,500	\$62,500	\$87,500	\$125,000	\$175,000	
Transportation Budget (13%)		\$2,600	\$3,900	\$5,525	\$8,125	\$11,375	\$16,250	\$22,750	

Table 16: Membership fees charged by different car sharing providers. Fees may vary within providers due to multiple value plans offered.

Car Sharing Provider	Membership fee
car2go	\$0
PhillyCarShare	\$35/\$125
City CarShare	\$50/\$120/\$240
I-GO Car Sharing	\$0/\$180/\$360
Zipcar	\$0/\$60



(a) Available car sharing lots in the greater Midtown area (Zipcar, 2012b).



(b) Aerial representation of the covered area.

Figure 30: Geographic area that Zipcar covers in the greater Midtown area, Fulton County, GA.

Appendix C

C1. Proofs.

Proof of Proposition 1.

$$\begin{aligned}
\frac{\partial \Pi}{\partial e_1} &= f \frac{\partial p}{\partial e_1} (1 - \delta q) - fp\delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_1} - c_1 \\
&= f \frac{\partial p}{\partial e_1} (1 - \delta q) + fp\lambda\delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} - c_1 \leq 0 \tag{61} \\
\frac{\partial^2 \Pi}{\partial^2 e_1} &= f \frac{\partial^2 p}{\partial^2 e_1} (1 - \delta q) - f \frac{\partial p}{\partial e_1} \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_1} + f \frac{\partial p}{\partial e_1} \lambda \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} \\
&\quad + fp\lambda\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_1} \\
&= f \frac{\partial^2 p}{\partial^2 e_1} (1 - \delta q) + 2f \frac{\partial p}{\partial e_1} \lambda \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} - fp\lambda^2\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} < 0 \\
\frac{\partial^2 \Pi}{\partial e_1 \partial e_2} &= -f \frac{\partial p}{\partial e_1} \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_2} + fp\lambda\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_2} \\
&= -f \frac{\partial p}{\partial e_1} \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} + fp\lambda\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} > 0 \\
\frac{\partial \Pi}{\partial e_2} &= -fp\delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_2} - c_2 \\
&= -fp\delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} - c_2 \leq 0 \tag{62} \\
\frac{\partial^2 \Pi}{\partial^2 e_2} &= -fp\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} \frac{\partial (e_2 - \lambda e_1)}{\partial e_2} \\
&= -fp\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} < 0 \\
\frac{\partial^2 \Pi}{\partial e_2 \partial e_1} &= \frac{\partial^2 \Pi}{\partial e_1 \partial e_2} \quad (\text{by Young's Theorem})
\end{aligned}$$

The second principal minor of the Hessian can be calculated as follows:

$$\begin{aligned}
|H| = |H_2| &= \frac{\partial^2 \Pi}{\partial^2 e_1} \frac{\partial^2 \Pi}{\partial^2 e_2} - \left(\frac{\partial^2 \Pi}{\partial e_1 \partial e_2} \right)^2 \\
&= -fp\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} \left(f \frac{\partial^2 p}{\partial^2 e_1} (1 - \delta q) + 2f \frac{\partial p}{\partial e_1} \lambda \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} - fp\lambda\delta \frac{\partial^2 q}{\partial^2 e_1} \right) \\
&\quad - \left(-f \frac{\partial p}{\partial e_1} \delta \frac{\partial q}{\partial (e_2 - \lambda e_1)} + fp\lambda\delta \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} \right)^2
\end{aligned}$$

$$\begin{aligned}
&= -f^2 \delta p \frac{\partial^2 p}{\partial^2 e_1} \frac{\partial^2}{\partial^2 (e_2 - \lambda e_1)} + f^2 \delta^2 p \frac{\partial^2 p}{\partial^2 e_1} q \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} - f^2 \delta^2 \left(\frac{\partial p}{\partial e_1} \frac{\partial q}{\partial (e_2 - \lambda e_1)} \right)^2 \\
&= -f^2 \delta \left(p \frac{\partial^2 p}{\partial^2 e_1} \frac{\partial^2 q}{\partial (e_2 - \lambda e_1)} (1 - \delta q) + \delta \left(\frac{\partial p}{\partial e_1} \frac{\partial q}{\partial (e_2 - \lambda e_1)} \right)^2 \right) > 0 \Leftrightarrow \\
&\delta < \frac{p \frac{\partial^2 p}{\partial^2 e_1} \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)}}{pq \frac{\partial^2 p}{\partial^2 e_1} \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)} - \left(\frac{\partial p}{\partial e_1} \frac{\partial q}{\partial (e_2 - \lambda e_1)} \right)^2} \doteq \hat{\delta} > 0
\end{aligned}$$

When $\delta < \hat{\delta}$ the first order conditions (61) and (62) are also sufficient. Solving $\frac{\partial \Pi}{\partial e_1} = 0$ and $\frac{\partial \Pi}{\partial e_2} = 0$ simultaneously, we obtain

$$\left(1 - \delta q [e_2^* - \lambda e_1^*] \right) f \frac{\partial p}{\partial e_1} \Big|_{e_1=e_1^*} = c_1 + \lambda c_2.$$

Proof of Proposition 2.

$$\begin{aligned}
\frac{\partial e_1^*}{\partial c_1} &= \frac{\begin{vmatrix} -\frac{\partial G_1}{\partial c_1} & \frac{\partial G_1}{\partial e_2^*} \\ -\frac{\partial G_2}{\partial c_1} & \frac{\partial G_2}{\partial e_2^*} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} 1 & \frac{\partial^2 \Pi}{\partial e_1^* \partial e_2^*} \\ 0 & \frac{\partial^2 \Pi}{\partial^2 e_2^*} \end{vmatrix}}{|J|} < 0 \\
\frac{\partial e_2^*}{\partial c_1} &= \frac{\begin{vmatrix} \frac{\partial G_1}{\partial e_1^*} & -\frac{\partial G_1}{\partial c_1} \\ \frac{\partial G_2}{\partial e_1^*} & -\frac{\partial G_2}{\partial c_1} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} \frac{\partial^2 \Pi}{\partial^2 e_1^*} & 1 \\ \frac{\partial^2 \Pi}{\partial e_2^* \partial e_1^*} & 0 \end{vmatrix}}{|J|} < 0 \\
\frac{\partial e_1^*}{\partial c_2} &= \frac{\begin{vmatrix} -\frac{\partial G_1}{\partial c_2} & \frac{\partial G_1}{\partial e_2^*} \\ -\frac{\partial G_2}{\partial c_2} & \frac{\partial G_2}{\partial e_2^*} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} 0 & \frac{\partial^2 \Pi}{\partial e_1^* \partial e_2^*} \\ 1 & \frac{\partial^2 \Pi}{\partial^2 e_2^*} \end{vmatrix}}{|J|} < 0 \\
\frac{\partial e_2^*}{\partial c_2} &= \frac{\begin{vmatrix} \frac{\partial G_1}{\partial e_1^*} & -\frac{\partial G_1}{\partial c_2} \\ \frac{\partial G_2}{\partial e_1^*} & -\frac{\partial G_2}{\partial c_2} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} \frac{\partial^2 \Pi}{\partial^2 e_1^*} & 0 \\ \frac{\partial^2 \Pi}{\partial e_2^* \partial e_1^*} & 1 \end{vmatrix}}{|J|} < 0
\end{aligned}$$

Proof of Proposition 3.

$$\begin{aligned}
\frac{\partial e_1^*}{\partial f} &= \frac{\begin{vmatrix} -\frac{\partial G_1}{\partial f} & \frac{\partial G_1}{\partial e_2^*} \\ -\frac{\partial G_2}{\partial f} & \frac{\partial G_2}{\partial e_2^*} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} -c_1/f & \frac{\partial^2 \Pi}{\partial e_1^* \partial e_2^*} \\ -c_2/f & \frac{\partial^2 \Pi}{\partial^2 e_2^*} \end{vmatrix}}{|J|} > 0 \\
\frac{\partial e_2^*}{\partial f} &= \frac{\begin{vmatrix} \frac{\partial G_1}{\partial e_1^*} & -\frac{\partial G_1}{\partial f} \\ \frac{\partial G_2}{\partial e_1^*} & -\frac{\partial G_2}{\partial f} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} \frac{\partial^2 \Pi}{\partial^2 e_1^*} & -c_1/f \\ \frac{\partial^2 \Pi}{\partial e_2^* \partial e_1^*} & -c_2/f \end{vmatrix}}{|J|} > 0
\end{aligned}$$

Proof of Proposition 4.

$$\begin{aligned}
\frac{\partial e_1^*}{\partial \lambda} &= \frac{\begin{vmatrix} -\frac{\partial G_1}{\partial \lambda} & \frac{\partial G_1}{\partial e_2^*} \\ -\frac{\partial G_2}{\partial \lambda} & \frac{\partial G_2}{\partial e_2^*} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} f\delta \left(\frac{\partial q}{\partial e_1^*} \frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} e_1^* + p \frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} - p\lambda \frac{\partial^2}{\partial^2 (e_2^* - \lambda e_1^*)} e_1^* \right) & \frac{\partial^2 \Pi}{\partial e_1^* \partial e_2^*} \\ f p \delta \frac{\partial^2 q}{\partial (e_2^* - \lambda e_1^*)} e_1^* & \frac{\partial^2 \Pi}{\partial^2 e_2^*} \end{vmatrix}}{|J|} \\
&= \frac{f^2 \delta^2 p^2 \frac{\partial q}{\partial e_1} \frac{\partial^2 q}{\partial^2 (e_2 - \lambda e_1)}}{|J|} < 0 \\
\frac{\partial e_2^*}{\partial \lambda} &= \frac{\begin{vmatrix} \frac{\partial G_1}{\partial e_1^*} & -\frac{\partial G_1}{\partial \lambda} \\ \frac{\partial G_2}{\partial e_1^*} & -\frac{\partial G_2}{\partial \lambda} \end{vmatrix}}{|J|} = \frac{\begin{vmatrix} \frac{\partial^2 \Pi}{\partial^2 e_1^*} & f\delta \left(\frac{\partial p}{\partial e_1^*} \frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} e_1^* + p \frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} - p\lambda \frac{\partial^2}{\partial^2 (e_2^* - \lambda e_1^*)} e_1^* \right) \\ \frac{\partial^2 \Pi}{\partial e_2^* \partial e_1^*} & f p \delta \frac{\partial^2 q}{\partial (e_2^* - \lambda e_1^*)} e_1^* \end{vmatrix}}{|J|} \\
&= \frac{f^2 \delta \left(-\delta \frac{\partial p}{\partial e_1^*} \left(p + e_1^* \frac{\partial p}{\partial e_1^*} \right) \left(\frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} \right)^2 + p \left(-e_1^* \frac{\partial^2 p}{\partial^2 e_1^*} (1 - \delta q) + \delta \lambda p \frac{\partial q}{\partial e_1^*} \right) \frac{\partial^2 q}{\partial^2 (e_1^* - \lambda e_2^*)} \right)}{|J|}
\end{aligned}$$

The sign of $\frac{\partial e_2^*}{\partial \lambda}$ warrants further investigation. Specifically, we can show

$$\begin{aligned}
\frac{\partial e_2^*}{\partial \lambda} &> 0 \Leftrightarrow \\
\delta &< \frac{e_1^* p \frac{\partial^2 p}{\partial^2 e_1^*} \frac{\partial^2 q}{\partial^2 (e_2^* - \lambda e_1^*)}}{-\frac{\partial p}{\partial e_1^*} \left(p + e_1^* \frac{\partial p}{\partial e_1^*} \right) \left(\frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} \right)^2 + p \left(e_1^* \frac{\partial^2 p}{\partial^2 e_1^*} q + \lambda p \frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} \right) \frac{\partial^2 q}{\partial^2 (e_2^* - \lambda e_1^*)}} \doteq \bar{\delta} > 0.
\end{aligned}$$

We are now interested in identifying the relationship between $\hat{\delta}$ and $\bar{\delta}$. With some simple but rather tedious algebraic manipulations we can establish that,

$$\begin{aligned}
\bar{\delta} - \hat{\delta} &= p \frac{\partial^2 p}{\partial^2 e_1^*} \frac{\partial^2 q}{\partial^2 (e_2^* - \lambda e_1^*)} \frac{1}{\left(\frac{\partial p}{\partial e_1^*} \right)^2 \left(\frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} \right)^2 - p \frac{\partial^2 p}{\partial^2 e_1^*} q \frac{\partial^2 q}{\partial^2 (e_2^* - \lambda e_1^*)}} \\
&+ p \frac{\partial^2 p}{\partial^2 e_1^*} \frac{\partial^2 q}{\partial^2 (e_2^* - \lambda e_1^*)} \frac{e_1^*}{-\frac{\partial p}{\partial e_1^*} \left(p + e_1^* \frac{\partial p}{\partial e_1^*} \right) \left(\frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} \right)^2 + p \left(e_1^* \frac{\partial^2 p}{\partial^2 e_1^*} q + \lambda p \frac{\partial q}{\partial (e_2^* - \lambda e_1^*)} \right) \frac{\partial^2 q}{\partial^2 (e_2^* - \lambda e_1^*)}} \\
&< 0 \quad \forall \lambda > 0.
\end{aligned}$$

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